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ACADEMICIAN NIKOLAY SERGEYEVICH SHATSKIY (1895-1960)[1]

On August 1, 1960, Soviet geology lost one of its champions in the person of N. S. Shatskiy, a talented scientist, brilliant teacher, outstanding speaker, and a charming person, who suddenly passed away in his 65th year.

N. S. Shatskiy was born August 28, 1895, in Moscow, to the family of an employee. Upon graduation from gymnasium, in 1913, he matriculated in the natural science section of the Physical Sciences and Mathematics Department of the Moscow State University, where he began his study of geology under Academician A. P. Pavlov. N. S. Shatskiy became interested in geology as early as the gymnasium when, guided by naturalist A. A. Yegorov, a family friend, he collected Middle Carboniferous and Jurassic fossils in the Moscow area. In the university, brillant lectures and interesting field trips organized by Academician A. P. Pavlov definitely influenced the vocational choice of N. S. Shatskiy. While in school, he carried on his first independent work, in 1916, on the hydrogeology of the Volga region.

His schooling and geologic work were interrupted by the call to the Army, in 1916. After the Great October Revolution, he fought in the Red Army ranks and was assigned to reserves in 1921, upon request of the Moscow Mining Academy, where he resumed his teaching and scientific work. As early as 1924, he lectured on the geology of Siberia; in 1929, on geotectonic and structural geology; and later he taught historical geology and the geology of the U. S. S. R. in the Moscow Geological Exploration Institute.

Along with teaching, N. S. Shatskiy carried on intensive scientific activity. His first work, "The Balykley Graben and Faults of the Lower Volga Region", was published in 1922; it presented the results of his field work as a student.

Beginning in 1922, N. S. Shatskiy worked on the geological committee on the Kursk Magnetic Anomaly (KMA); then, in 1926-1934, at the State Petroleum Research Institute and Petroleum Exploration Institute. During these years, he carried on field work in the northern and southeastern Caucasus; its results are presented in a number of his works.

With the transfer of the Academy of Sciences to Moscow, N. S. Shatskiy was invited to work at its Geological Institute.

In 1935, he organized the Tectonics Section, leading it until 1956. It was here that he brought together a large creative group and set up the largest school of Soviet tectonists.

In 1943, N. S. Shatskiy was elected Corresponding Member and in 1953 Active Member of the Academy of Sciences U. S. S. R. ; in 1956 he became Director of its Geological Institute to the organization and development of which he dedicated all his ability and energy.

N. S. Shatskiy was a geologist in the broad sense, interested as he was in the field of tectonics, stratigraphy, lithology, and the history of geologic science, making notable contributions to each one.

Having started as a field geologist, N. S. Shatskiy worked for a few years in the Volga region, the Kaluga Oblast', Donets Basin, and the Caucasus. In that period, he worked out in detail the stratigraphy of Upper Cretaceous and Paleogene deposits of the Donets Basin (1924). That was over 35 years ago, but his stratigraphic conclusions and correlations are still valid.

In carrying out geological surveying in the northern Caucasus and Transcaucasus and delving into the oil prospects of assorted local formations, N. S. Shatskiy emphasized their stratigraphy, as he had done in the Donbas. He studied the constitution of the Maykop sequence, the Khadum stage, and other divisions of the Paleogene, and subdivided them into horizons.

Even these works revealed the masterly approach to stratigraphic analysis which was so

[1]Akademik Nikolay Sergeyevich Shatskiy.

conspicuous in later works of N. S. Shatskiy on the stratigraphy of the Precambrian and Paleozoic of the Russian platform and adjacent provinces.

Cognizant of the fact that there is an immense time break between the Jotnian and Lower Cambrian of the Baltic Shield, N. S. Shatskiy came to the conclusion that this break corresponds to ancient formations at the base of the sedimentary mantle in the Russian platform and the so-called "barren formations" on the west slope of the Bashkirian Urals. In 1945, he designated these deposits as a major stratigraphic unit corresponding to an era, such as Paleozoic, Mesozoic, and Cenozoic. He named it the Rhyphean, after Rhypheus, an ancient name for the Urals. He emphasized that Sinian deposits of the Chinese People's Republic correspond only to a portion of the Rhyphean, being one of its systems. This group is characterized by the simplest organic forms, with algae playing a leading part. The Rhyphean era appears to have lasted a few hundred million years.

Thus, to N. S. Shatskiy belongs an outstanding discovery in the field of stratigraphy. This alone would have been enough to perpetuate his name among the world's geologists.

This brief review is inadequate for assessing the many facets of N. S. Shatskiy's creative work in the field of tectonics which was his life-long favorite subject. A recognized creator of the Soviet tectonic school, he was not only an outstanding theoretician but also an initiator of many new methods and trends in solving of tectonic problems. Creative daring and striving after the new are the essence of his scientific testament. Another feature is that N. S. Shatskiy's works in regional tectonics, with a few exceptions, are closely related to general theoretical considerations, always original, definite, and penetrating. This is why they have been and still are so valuable in charting new trends and in the practice of forecasting the presence of industrial minerals. Long before the publication of his works, N. S. Shatskiy would bring them before the judgment of the geological fraternity, in brilliant talks which never failed to bring out a large audience. His ideas, even before their publication, became known rapidly and exercised a powerful and fruitful influence on the scientific and industrial activities of Soviet geologists.

In an early period of his work, N. S. Shatskiy described the morphology of numerous tectonic structures he had studied (the Volga region, the Caucasus, Donbas) and was an innovator of the tectonic study method. He developed a concept that formations and facies depend on tectonic and erosional relief, the concept which now is the basis of any analysis of the origin of geosynclinal and platform structural provinces. His study of formations and facies led him to an extremely important conclusion on the duration of major folding. This conclusion was published in 1924, i. e., prior to the publication of works by German geologists R. Bertling, H. Betcher (1925-1930), and others, which are often referred to as sources for the ideas on the duration of folding contemporaneous with sedimentation, in coal basins. Thus even in his early works, N. S. Shatskiy considered structures in their historical aspect, as closely related to changes in the composition and thickness of sediments.

In 1932, N. S. Shatskiy published a major tectonic work on the synthesis of the Siberian platform and the folded structures fringing it. This was the work of an accomplished master of tectonic analysis, endowed with the gift of scientific insight. At that time, data on the geology of eastern Siberia were quite scarce, fragmentary, and inexact. Because of that, N. S. Shatskiy, working on the tectonics of an immense province, was virtually denied the benefits of the paleogeographic method so brilliantly developed and applied by A. P. Karpinskiy and A. D. Arkhangel'skiy in a structural analysis of the well-known Russian platform. In dealing with Siberian structures, N. S. Shatskiy boldly introduced new methods of structural analysis for major elements of the earth's crust and the comparative tectonic method. The structural method is based on a careful analysis of relationship, in space and time, of different tectonic forms joined to one another and often belonging to most diverse systematic categories (trend of folding and non-folding deformations, their magnitude, morphology, relative elevation, boundary lines, internal structure, the manner of coupling, etc.). Comparative tectonic analysis, as its name suggests, consists of comparing similar tectonic forms, often far from one another, thereby revealing their common and individual features in order to determine regularities in their origin and development.

Strictly speaking, N. S. Shatskiy was the first to define the Siberian platform as now understood and accepted, virtually without any corrections, by all geologists. By comparing the Siberian and the Russian platforms, he achieved a tectonic subdivision of this immense region, identifying its main structural forms and determining their relationship to the surrounding structures of various ages. He brilliantly analyzed the hypothesis of the so-called "Ancient Pate of Asia" and has demonstrated its utter inconsistency. It turned out that "the oldest", primordial horizons of the "Ancient Pate" belong to folded formations of different ages but mostly younger than the crystalline basement of the Siberian platform. The same work first established the existence of an independent folding cycle developed in late Upper Proterozoic time (now Rhyphean) and terminated in the lower half of the Cambrian. Later on, N. S. Shatskiy named this cycle the Baikalian, with its folded

structures, the baikalids. These concepts and terms are firmly grounded in Soviet geology and have begun to gain international recognition.

A new period in tectonic study was initiated by N. S. Shatskiy's work on tectonics of the Russian and other ancient platforms. In the course of many years, he published a series under the general heading Comparative Tectonics of Ancient Platforms (1945, 1946, 1947, 1948, 1952, and 1955). This classic series revealed especially well the outstanding ability of a scientist whose theoretical generalizations gained in depth with each passing year, as he developed his scientific insight. The same series reflected the final development of the structural and comparative tectonic methods on which they were based.

N. S. Shatskiy has demonstrated that ancient pre-Rhyphean platforms are outlined on all sides by rectilinear faults penetrating deep into the mantle. These faults, often concealed under sediments, are responsible for the jagged, zigzag platform outlines along which the platforms are joined to folded structures of various ages which fringe them. These fringe structures do not form smooth arcs, as formerly believed; they occur rather in jagged rectilinear segments of various lengths. N. S. Shatskiy attributed great importance in the formation of special types of platform structures to what he called "the interior platform angles". Originating in the projection of these internal angles into the platform body are new tectonic forms which he named marginal transverse structures. Present among them are a) marginal transverse flexures, such as the Chernyshev swell in the Russian platform; b) marginal transverse synclises such as the Ottawa on the Canadian shield, and the Permian Delaware basin of the North American platform; c) marginal transverse grabens, as exemplified by the Oslo graben; and d) marginal transverse systems best represented by the Greater Donbas and the Wichita (North American Platform). N. S. Shatskiy paid especial attention to comparative study of the tectonics and origin of marginal transverse systems. According to him, such systems originate in the tension and breaking up of the platform basement in a province adjacent to its internal angle, as the effect of movement in an adjacent geosynclinal system.

Marginal troughs and sutures are also most important. The formation of these longitudinal structures is closely related to the development features of platform structures of the first order, shields and blocks, and associated folded provinces. The marginal troughs of ancient platforms (the Uralian and Verkhyansk foredeeps) always adjoin blocks, i. e., tectonic forms with an inherited downward movement at the time of closure and general uplift in the adjacent geosynclinal system, while marginal sutures (faults) always separate the inherently uplifted forms (shields) from the folded zones. Marginal faults are never formed in such platform areas. Marginal transverse systems and troughs are characterized by geologic formations and internal structure of their own.

In analyzing the formation conditions of syneclises and anticlises, N. S. Shatskiy came to the important conclusion that syneclises are actively downwarped forms over blocks and shields, while anticlises are passive uplifts residual to this subsidence. As the cause for such active downwarping of syneclises, he postulated a compaction of deep-seated material in the crust, and perhaps in the mantle, under these forms.

The next lower order of structures in ancient platforms, as defined by N. S. Shatskiy, are placosynclines and placanticlines, often forming systems of swells which usually complicate the syneclise slopes. Such forms originate in movements along the basement faults. Major oil fields are known to be associated with these structures.

N. S. Shatskiy also worked on the idea of deep dislocations involving both the platforms and the folded provinces. He demonstrated in the example of the southeastern margin of the Russian platform and the Caucasus that such dislocations include longitudinal subsidences involving both a platform and an Alpine geosynclinal province.

In his last, still unpublished work on ancient platforms, he again took up the problem of marginal transverse systems. He designated them as an independent type of tectonic platform structure which he named the aulacogenes, from the Greek for "trench-born". He designated as typical aulacogenes of the Russian platform the Greater Donbas trough, the so-called Polish-Danish trench, and the Timan Range — Kanin Peninsula dislocations.

Thus, N. S. Shatskiy has initiated a new trend in the theory of platforms and folded provinces, a trend which is being pursued by his students and followers.

His well-known monograph, "Outline of the Tectonics of the Volga-Urals Petroleum Province and the Adjacent Part of the South Uralian West Slope" appeared in 1945. Its subject matter goes well beyond a mere regional study, inasmuch as it includes not only general problems in the tectonics of ancient platforms and folded provinces but the first formulation of the theory of geologic formations; in addition, the new Rhyphean group is designated for the Precambrian. For this outstanding scientific work, N. S. Shatskiy was awarded the 1946 Stalin Prize.

One of the prominent achievements of N. S. Shatskiy was the making of tectonic maps; the

development of its scientific principles and methods took up much of his time and energy. As early as 1933, a scheme of tectonic classification for the U. S. S. R. was appended to the joint work by A. D. Arkhangel'skiy and N. S. Shatskiy on the main tectonic features in the immense expanse of our country. Taken as a basis of this scheme was the principle of differentiation of the crust into ancient Precambrian platforms and their fringing geosynclinal provinces; the latter were subdivided by their latest and most intensive folding into Paleozoic, Mesozoic, and Cenozoic. This classification reflects the historical approach, characteristic of both men, not only to tectonic differentiation but to the understanding of general regularities in the structures of the crust.

Such an approach was further developed in N. S. Shatskiy's "Tectonics of the Arctic" (1935), accompanied by a tectonic map not only for the Arctic but for large areas to the south, in both hemispheres. This map presents an essentially new tectonic classification of the Arctic, with provinces of Precambrian and Baikalian folding, and the areas of developments of the Caledonian, Hercinian, Mesozoic, and Cenozoic foldings.

Applying the same principles, and continuing to develop his method of compiling the map and the legend, N. S. Shatskiy, in collaboration with his co-workers, completed in 1952 the first tectonic map of the U. S. S. R., on a scale of 1:4, 000, 000. This map represented a graphic synthesis of our knowledge in the field of theoretical tectonics as well as in regional tectonics of the immense area of our country. A more detailed differentiation into structural forms, as well as a graphic representation of their development history, was achieved by designating the several structural stages of folded structures, and by indicating the crystalline basement depth, along with contours on several stratigraphic levels of the sedimentary mantle, for the platforms. This tectonic map of the U. S. S. R. received high praise, both at home and abroad.

A second edition of this map, at a scale of 1:5, 000, 000, was published in 1956, with a legend published the year after. This map had more detail than the preceding one and showed intrusions of various compositions and ages.

For the creation of this map, N. S. Shatskiy was awarded the 1957 Lenin Prize; the map was awarded the Grand Prix of the 1959 Brussels International Exposition.

N. S. Shatskiy's views in the field of general theoretical tectonics are marked by their exceptional logic, close cohesion of principles, and consistency. He was not partial to all-embracing tectonic hypothesis. The hypothesis of A. Wegener, that champion of mobilists, alone, bothered him somewhat in that it solved the cardinal problem of the formation of geosynclines in a manner different from his own.

N. S. Shatskiy preferred to work in the field of "analytic" rather than "synthetic" tectonics, to use his own expression, by applying rigorous historical geologic methods of study, on the basis of reliable empirical data. Most of his brilliant works in this field deal with problems of regional and comparative tectonics, with general tectonics taking second place. At the same time, his credo in the field of theoretical tectonics is very clearly exposed in a number of articles, reports, lectures, and discussions, in the last 25 years.

N. S. Shatskiy was a most talented and consistent advocate of the idea of the evolution of geologic phenomena, from individual tectonic structures to the crust as a whole. He rejected cyclicity, the reversibility of evolution, and the alternation of epeirogenic and orogenic epochs.

The development of these ideas determined the great interest N. S. Shatskiy had in the work of Charles Darwin, which contributed to the clarification of his own concepts. As often emphasized by N. S. Shatskiy, the evolution of geologic phenomena in the course of time did not proceed at the same rate; structures underwent qualitative change, along with changes in the nature of formations and the movements of the crust. These movements were accelerated or slowed down in different provinces, but there was no such thing as planetary and very rapid tectonic phases as H. Stille understood them. N. S. Shatskiy defended ardently this concept of his (sic), in his books and articles, especially in his well known paper on neocatastrophism, read before the Moscow International Geological Congress of 1937. N. S. Shatskiy's views on the origin of folding are based on his criticism of Stille and his school with their concept of orogenic phases of folding, separated by long epochs of other movements, known as epeirogenic or oscilatory. As exposed by N. S. Shatskiy, Stille's ideas hark back to those of catastrophists of the first half of the XIX century (e. g., Ely de Beaumont); accordingly, they can be called, "neocatastrophic". The scientific basis for such concepts is an erroneous interpretation of angular unconformities, according to which the dip of a sequence below an unconformity originates after the deposition of its uppermost member. The truth is that folding can occur simultaneously with sedimentation, while angular unconformities occur only when the uplifted beds have been eroded to some extent. Considered by itself, folding is a long process commensurate with sedimentation.

N. S. Shatskiy applied the same idea of an evolutionary trend to his theory of geosynclines and platforms. He did not share the view that platforms become geosynclines. He believed

that the trend of evolution from geosynclines to platforms is a basic premise in the development of the crust.

There is, then, a growth of platform areas, and the Paleozoic through the Cenozoic should be regarded as a time essentially favoring the development of platforms, in contrast to an earlier geosynclinal period of embryonic platforms.

N. S. Shatskiy, a representative of the "analytic" trend of geologic thought, did not spend much time on the general problem of crustal movements with its many hypotheses; he has not left any complete study in that field. However, he did voice a quite definite opinion on that subject. He always adhered to the classic doctrine of stability (fixism), rejecting at the same time its popular and narrow interpretation which denies all horizontal movements of the crust. On the other hand, his total negation of the mobilism of A. Wegener's type was determined by his views that such concepts contradict what we do know about crustal structure. He believed that tectonic structures with an inherited long history of development, and especially the deep tectonic rifts, are related to crustal movement and evolution in very deep reaches of the sima mantle; for that reason, a "free floating" of sialic continents on a sima layer, which is the basis of Wegener's hypothesis, would be impossible.

In his well-known 1939 theses entitled "The Theoretical Front of Geotectonics", N. S. Shatskiy subdivided all crustal movements according to the types of structures originating in them. He differentiated epeirogenic movements involving large crustal segments; movements resulting in syneclises and anticlises; movements of geosynclines and geanticlines, i. e., orogenic movements; and finally folding movements. In later unpublished papers, he developed and refined these concepts.

The outstanding contribution of N. S. Shatskiy is his principle of inheritance which charts the extremely complex, long, and contradictory process of crustal development, at least, from Paleozoic time onward. This principle underlies his view that the Paleozoic, Mesozoic, and Cenozoic history of the earth is essentially a discrete, unbroken, and progressive process.

The concept of inherited and superimposed structures, first developed by N. S. Shatskiy in the study of central Kazakhstan and published in 1938, is a theoretical premise initiating a new trend in science. A number of investigations carried out by Soviet geologists in recent years bear testimony to its importance in the progress of tectonics. At the present time, it constitutes the basis for all work on the origin and development of tectonic structures in both geosynclinal and platform provinces.

Especially significant are the theoretical views of N. S. Shatskiy on the profound difference in tectonic structure and development of the Pacific and Atlantic segments of the earth. Supported by views of V. I. Vernadskiy and S. S. Smirnov on the peculiar features in the development of the Pacific zone, N. S. Shatskiy introduced many new concepts on the timing of principal epochs of folding in that part of the globe (Mesozoic and Cenozoic Kamchatka foldings) and on specific features of its igneous activity and metallogeny.

N. S. Shatskiy paid much attention to the problems of lithology. This led him to the development of a theory of geologic formations. The study of formations, or natural associations of rocks, would seem to be a merely lithologic problem; however, N. S. Shatskiy always stressed the fact that the notion of formations belongs to general geology. Without denying the value of special lithologic study, he pointed out that "an understanding of formations in their broader interpretation as geologic bodies is achieved only by geologic study, primarily by means of all available mapping methods" (1955, page 8).

He applied his interpretation of geologic formations not only in solving lithologic problems such as the origin of individual rocks but also in the field of general and regional tectonics, the theory of industrial minerals and regularities in the distribution of ores, and finally in solving such problems as the Cambrian-Rhyphean boundary.

Chronologically, N. S. Shatskiy's works on geologic formations are divisible into three groups. From 1939 to 1953, he defined the term, cited examples of individual formations, and outlined the development of his theory. From 1954 to 1955, he described manganese- and phosphorite-bearing formations, touching at the same time on general principles in the study of formations. Finally, in 1960, he formulated his views on this subject in a special paper. We shall pause briefly to review his definitions.

From 1939 on, N. S. Shatskiy repeatedly stated his definition of formations, with but slight variations. It is as follows: "Sedimentary formations are natural bodies (combinations, associations) or rocks whose individual members are interrelated paragenetically both laterally and vertically in a stratigraphic sequence".

Attempts at distinguishing natural rock associations, more or less similar to N. S. Shatskiy's geologic formations, are as old as geology itself. However, the urgency of such distinctions became especially clear in recent years, as witness the numerous works published in the U. S. S. R. and abroad. The originality of

N. S. Shatskiy's definition, which has earned wide recognition, is in the introduction of a new notion of the paragenesis of rocks in addition to the familiar notions of the paragenesis of minerals and elements. The meaning and significance of such a study method is well expressed by its author, himself; this definition is free of any theoretical premises; it suggests a method of study and the place of formations in a continuous geologic series: rock — genetic type of deposits — formation — formation series.

Very characteristic of the N. S. Shatskiy style of work is that he follows his new concepts and definitions with an illustration of a method for their study; this method, itself, is often new. A feature in his latest definition of formations is emphasis on the spatial relationship of rocks, i. e., the structure of the formation.

This is immediately followed by a study of various types of relationships between rocks, such as facies series and associations, "paternal" and "allophylian", principal and secondary members of formations, "vicarious" members of facies series, etc. The study of structural types of formations along with other topics outlined in the last paper by N. S. Shatskiy shows that his life came to an end at the time of an intensive effort to develop the study of geologic formations.

The inspired scientific activity of Academician N. S. Shatskiy was always closely related to problems bearing on the development of the state economy.

In the early twenties, when the Soviet of People's Commissars stressed the importance of the Kursh magnetic anomaly, N. S. Shatskiy carried out a most valuable study of the geology of Upper Cretaceous and Tertiary deposits on the north margin of the Donets Basin. "Without a clear idea of the stratigraphy and tectonics of the Donets beds of Mesozoic age, it is impossible to determine either the probable composition of rocks present in the south of the Kursk magnetic anomaly or the position of a zone of normal faults and flexures which bound in the south that block of Precambrian rocks which carries ferruginous quartzites in the northern part of the Kursk Oblast'" (1924). N. S. Shatskiy maintained his interest in the magnetic anomaly in the following years; in 1950 he again tackled this problem as leader of the Kursk magnetic anomaly project in the former Institute of Geologic Sciences, Academy of Sciences, U. S. S. R.

N. S. Shatskiy was particularly interested in the oil prospects of our country. His extended studies, in the twenties, of petroleum areas in the northern and northeastern Caucasus are well known. In 1931 he worked in the south Baikal region, in the exploration for oil and gas. As a result, he published an important report to the effect that "true nappes of metamorphics over Mesozoic and Cenozoic rocks are missing" in that area (1933).

In the same year, 1931, N. S. Shatskiy made a remarkable prediction of oil prospects for the Ukraine, when he proposed an amazingly bold hypothesis on the presence of salt dome structures in the area of Romny and Isachki. Seven years later, when this hypothesis was found to be true, he reviewed this subject at the Ukrainian Petroleum Conference, in Kiyev. This brilliant prediction has been fully substantiated in recent years; it demonstrated once more the effectiveness of geologic methods in solving the problems related to the growth of mineral reserves of the land.

No less remarkable were N. S. Shatskiy's general forecasts of oil fields in the northern and eastern parts of the Siberian platform. His first mention of this subject was in 1932, i. e., when the status of knowledge of those regions was quite poor.

In tackling the Siberian oil prospects, N. S. Shatskiy wrote that perhaps the most important indications for a search for oil are certain regularities in the distribution of oil showings and oil fields, depending on the regional geologic structure. It appears, then, that he perceived almost 30 years ago, that a broadening of the mineral raw-material base should proceed by way of studying regularities in mineral distribution, i. e., in the field to which he dedicated his last years.

During the Great Patriotic War, N. S. Shatskiy's work was closely related to the development of our most important petroleum province of the Second Baku. Outstanding among his publications of those years is his well-known "Outline of the Tectonics of the Volga-Ural Province", where he presents a brilliant analysis of that immense region.

In the mid-thirties, N. S. Shatskiy made a special study of the Bureya coal basin. The results were published (in cooperation with T. N. Davydova) in a paper "On the Mesozoic of the North Bureya Basin" (1937). This work became very important in the study of that region because of a new interpretation of its geologic history, different from that of earlier authors.

Academician N. S. Shatskiy was a brilliant expert on phosphorite, manganese, and iron-ore deposits.

As early as 1927, he published, in cooperation with A. D. Arkhangel'skiy and V. N. Krestovnikov, a collection, "Phosphorites of the U. S. S. R. ", in which he included a comprehensive article on Cenomanian and Tertiary phosphorites of the Dnepr-Donets trough, with an estimate of reserves. His remarkable study of "Phosphorite

Formations and a Classification of Phosphorite Deposits" was published in 1955.

In his last years, N. S. Shatskiy conducted his study of phosphorite, manganese, and iron deposits chiefly on the basis of the formation analysis method. This method, which he continually developed and perfected, enabled him to discover extremely important regularities in the spatial distribution and the conditions of formation of these ores. More specifically, he was first to publish a comprehensive analysis of the volcanic factor in their origin. He believed that the primary concentration of manganese in the crust is related chiefly to formations of the volcanic-siliceous group (1954). He assigned to the same group the phosphorite deposits originating under geosynclinal conditions.

An outstanding tectonist, N. S. Shatskiy understood well the relationship between tectonic study and geologic practice. He expressed it in the following plain words, in his 1937 article, "Twenty Years of Soviet Tectonics": "In the final account, the success of geotectonics depends on the economic development of a country, particularly on the development of its mining industry. Conversely, geotectonics in general, and structural geology in particular, are the most necessary elements in all exploration work for ores, mineral fuels, and mineral raw material."

All of the scientific work of N. S. Shatskiy carries out the truth of this statement.

This interpretation of geologic theory and practice enabled him to champion, when the time came, a new trend in geologic studies, extremely important for Communist building: the knowledge of regularities in the distribution of principal industrial minerals in the crust. In the last eight years, N. S. Shatskiy spent much effort in the organization of work in this field. His articles on phosphorites, along with his study related to the theory of formations, are directly related to the study of regularities in the distribution of industrial minerals.

At the present time, such studies are being conducted on an All-Union scale, and the credit for that belongs to N. S. Shatskiy. For a number of years (and several times a year) he was chairman of most instructive scientific sessions and conferences on various aspects of this momentous problem. He also was chief editor of the "Regularities in the Distribution of Industrial Minerals" (volumes 3, 4, and 5 are now in press).

Underscoring the importance of this work for the state economy, N. S. Shatskiy often pointed out that such efforts go far toward solving theoretical problems in geology, particularly the general theory of mineralization and the origin of rocks and ores.

The scope of interests of N. S. Shatskiy was not confined to geology alone. He devoted much time to the study of allied natural sciences, history, and philosophy. Such a broad scope of interest brought him a deeper understanding of the progress of geology, its current problems, and particularly its methods.

His brilliant studies in the history of science, such as his familiar monographs on R. Murchison, A. P. Karpinskiy, A. D. Arkhangel'skiy, and particularly on Charles Darwin, are marked by a deep insight into the scientific, philosophical, and social environments which molded the views of these men. In his historical studies, N. S. Shatskiy, alone among geologists, was able to relate the old achievements and the most recent progress and problems of modern science.

In analyzing the scientific heritage of Charles Darwin, he demonstrated how that scientist had overcome the narrow limitations of Lyell's orthodox actualism and had built up the notion of a general irreversible evolution of the organic world.

One of the paramount scientific-philosophical views of N. S. Shatskiy is a notion of the qualitatively irreversible evolution of all geologic processes on the earth's surface and in the crust. He believed that the most important achievement of Soviet geology has been in understanding of the irreversibility of sedimentary processes, tectonics, the nature of igneous activity, and other geologic processes. In so doing, he was armed with the powerful tool of his theory of geologic formations.

Opinions have been voiced in recent years to the effect that geology has outlived itself, to some extent, that its tools are obsolete, and that it is not likely to come up with anything substantially new bearing on the interpretation of the history and structure of the earth. Such views never failed to provoke a sharp retort from N. S. Shatskiy. He labored to demonstrate how fast purely geologic methods can be improved and how fast new and numerous geologic problems do appear. His was the deep conviction that we stand on the threshold of major discoveries in the field of geology.

He was busy writing a major work on his scientific-philosophical views, but his time was cut short. Our future task is a careful analysis and correlation of his individual publications as well as manuscript outlines, in order to present an over-all picture of his views on problems of geology and on science in general.

The organizational, editorial, teaching, and social activities of N. S. Shatskiy, too, were extensive. As a scientific organizer, he was active as the leader of the Tectonic Section which he had set up at the former Institute of Geologic Sciences, Academy of Sciences,

U. S. S. R.; as Acting Director of that Institute; and finally as Director of the Geological Institute, Academy of Sciences, U. S. S. R.; he also was leader in many interdepartmental commissions at the Geologic-Geographic Section and the Presidium of the Academy of Sciences, U. S. S. R.

Until his last days, N. S. Shatskiy was Chairman of the Commission on the Tectonic Map, where he had directed the making of a 1:2,500,000 tectonic map of Europe exhibited at the XXI Session of the International Geological Congress, Copenhagen, August 1960. As the outstanding tectonist, widely known abroad, he was elected President of the Sub-Commission for the Tectonic Map of the World, at the Mexican Session of the Congress.

In 1955-1959, N. S. Shatskiy was Chairman of the Interdepartmental Commission on Regularities in the Distribution of Industrial Minerals. He continued active in this field, to the last. At the same time he directed the Commission on the Geologic Study of the U. S. S. R., and was very active in work of the Commission on the Absolute-Age determination of Geologic Formations.

N. S. Shatskiy was equally active as an editor. He was chief editor of publications of the Geological Institute. He initiated publication of the "Tectonics of the U. S. S. R." series of which he was the editor. He also edited the capital work, "Problems in the Geology of Asia" and the first books of the "Regional Stratigraphy of the U. S. S. R." series. As already mentioned, he was editor of the very popular "Regularities in the Distribution of Industrial Minerals". He also edited the works of A. P. Pavlov, A. D. Arkhangel'skiy, books by B. Willis, A. Eardley, M. Kay, and many others.

At his initiative, and with him as editor, the Geological Institute has prepared and sent to press a two-volume publication of the method of study of tectonic structures.

N. S. Shatskiy performed a tremendous job of compiling and editing in the preparation of the Geologic Map of Eurasia at a scale of 1:6, 000, 000, 1954, highly appreciated by the Soviet and foreign geologic fraternity. He edited the 1:5, 000, 000 Tectonic Map of the U. S. S. R. (1956) and its legend.

From 1943 on, N. S. Shatskiy was a member of the editorial board for "Izvestiya" of the Academy of Sciences, U. S. S. R., Geologic Series; from 1923 on, he served in the same capacity for the Bulletin of the Moscow Society of Nature Students.

For over 40 years, N. S. Shatskiy dedicated himself to the training of new geologists. The walls of the Mining Academy and the Moscow Geologic Exploration Institute, where, until recently, he headed the section of Historical Geology, had witnessed the passage of hundreds of his students. Counted among them now are many noted scientists and practical geologists.

N. S. Shatskiy was busily engaged as an expert consultant in a number of important projects of state construction. For many years he was Chief Geologist of the "Hydroproject".

He was a member of the Moscow Society of Nature Students, the Hungarian, Czechoslovakian, and French Geological Societies, and the London Geological Society.

N. S. Shatskiy was the recipient of the Stalin (1946) and the Lenin (1957) Prizes. For his outstanding service to his country, he was awarded two Orders of Lenin, the Order of the Red Banner, and medals.

The great scientific heritage of N. S. Shatskiy, now part of Soviet and the world's science, will long be a basis for the further development of geologic science.

Section of Geologic-Geographic Sciences,
Academy of Sciences, U. S. S. R.
Geological Institute,
Academy of Sciences, U. S. S. R.
Editorial Board of Izvestiya,
Academy of Sciences, U. S. S. R.
Geologic Series

SCIENTIFIC WORKS OF ACADEMICIAN N. S. SHATSKIY[2]

1955

Geologic Sciences in the Moscow Society of Nature Students (on the 150th Anniversary of the Society). Byul. Mosk. Ob. Isp. Prir., otd. geol., t. 30 vyp. 5, pp. 125-132.

Kay, M., Geosynclines of North America. Transl. by N. S. Shatskiy and T. M. Dembo. Foreword by N. S. Shatskiy, Izd. inostr. lit., 192 pp., illustr., 4 maps.

On the Origin of the Pechelma Trough. Comparative Tectonics of Ancient Platforms. Article 5. Byul. Mosk. Ob. Isp. Prir., otd. geol., t. 30, vyp. 5, pp. 5-27, maps.

Phosphate-bearing Culm of the Karaganda Basin. Izv. Akad. Nauk SSSR, ser. geol., No. 3, pp. 48-57.

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[2]Addendum. See Izvestiya Akad. Nauk S. S. S. R., ser. geol., No. 5, 1955.

Phosphate-bearing Formations and a Classification of Phosphorite Deposits. In "Soveshchaniye po Osadochnym porodam", vyp. 2, M., Izd. Akad. Nauk SSSR, pp. 7-100, 2 maps.

1956

Academician Vladimir Afanas'yevich Obruchev (Obituary). Razvedka i Okrana Nedr, No. 8., pp. 61-63. In cooperation with Ye. V. Pavlovskiy.

Geologic map of Eurasia. Scale, 1:6, 000, 000. Compiled in 1954, directed and edited by Acad. N. S Shatskiy, in cooperation with A. Kh. Ivanov, and V. M. Sinitsin. M., Izd. GUGK, 6 sheets.

Academician V. A. Obruchev, a Hero of Socialist Labor (Obituary). Izv. Akad. Nauk SSSR, ser. geol., No. 6, pp. 6-11, photo. In cooperation with D. I. Shcherbakov et al.

Tectonic Map of the USSR and Adjacent Countries, scale 1:5, 000, 000. N. S. Shatskiy, Chief Editor. M., Gosgeoltekhizdat. 9 sheets.

Types de gisements des phosphorites. Dans: Resúmenes de los trabajos presentados XX International Geological Congress, Mexico. p. 101. Text in French.

1957

Paleozoic Spores in the Krivoy Rog Series of the Ukrainian Precambrian (On the article by A. M. Ishchenko: The Age of the Krivoy Rog Series). Information letter, Inst. geol nauk Akad. Nauk SSSR, 1957, January). Izv. Akad. Nauk SSSR, ser. geol., No. 4, p. 119-120.

The Study Prospects in the Verkhoyansk Front Marginal Trough. Promyshlenno-ekonom. gazeta, No. 14 (158), Febr. 1, p. 4.

Tectonic Map of the USSR and Adjacent Countries, 1:5, 000, 000. Legend. Academician N. S. Shatskiy, Chief Editor for Map. Legend by N. S. Shatskiy and A. A. Bogdanov. M., Gosgeoltekhizdat, 79 pp. one map sheet.

1958

Regularities in the Distribution of Industrial Minerals. Collection. Executive Editor, N. S. Shatskiy. M., Akad. Nauk SSSR, v. 1, 532 pp; v. 2, 540 pp.

Scientific Works of M. S. Shvétsov. Tr. Mosk. geol. -razv. inst. v. 33, pp. 5-8; photo.

Grundzüge des Tektonischen Baues der Sowjetunion. Berlin, Akad. Verlag. 84 pp. in cooperation with A. A. Bogdanov.

Les relations du Cambrien avec la Protérozoique et les plissements Baikaliens. Dans: Les rélations entre Précambriaen et Cambrien. Paris. (Coll. int. du C. N. R. S., v. 76).

1960

Geology in the Investigations by Charles Darwin. Byul. Mosk. Ob. Isp. Prir. otd. Geol. v. 35, vyp. 1, pp. 3-24.

Paragenesis of Sedimentary and Volcanic Rocks and Formations. Izv. Akad. Nauk SSSR, ser. geol., No. 5, pp. 3-23.

Principles of Stratigraphy of Upper Cambrian and the Extent of the Rhyphean Group. In "Stratigrafiya Pozdnego Dokambriya", M., pp. 5-15 (XXI Session Intern. Geol. Congr., Probl. 8).

Natal'ya Vasil'yevna Frolova (Obituary). In cooperation with D. S. Korzhinskiy et al. Izv. Akad. Nauk SSSR, ser. geol. No. 9, pp. 165.

THE ABSOLUTE GEOCHRONOLOGIC AGE SCALE FROM 1960 DATA OF USSR LABORATORIES[1]

Voluminous material was gathered by geochronologic laboratories of the U. S. S. R. during years of research work. On the basis of this material, the Commission for the Absolute-Age Determination of the Section of Geologic and Geographic Sciences, at the Academy of Sciences, U. S. S. R. could not proceed with its systematization.

The Ninth Session of the Commission, held in Leningrad, in June, 1960, was called for the special purpose of compiling an absolute geochronologic age scale. The Session designated a commission consisting of D. I. Shcherbakov, G. D. Afanas'yev, I. Ye. Starik, N. P. Semenenko, S. V. Obruchev, V. I. Baranov, G. P. Bagdasaryan, M. A. Garris, E. K. Gerling, L. V. Komlev, V. S. Koptev-Dvornikov, A. Ya. Krylov, L. N. Ovchinnikov, N. I. Polevaya, Yu. Ir. Polovinkina, M. M. Rubinshteyn, and A. I. Tugarinov. This commission, having considered data from key points as presented by individual laboratories, submitted the geologic scale given below. It was approved by the Commission as the 1960 scale.

The scale revealed that in some instances different age figures had been obtained for geologically synchronous Paleozoic formations from different regions (as determined by local geologists).

In the opinion of some members of the Commission, supported by students of Kazakhstan and to some extent by the data of collaborators in the Institute of Geochemistry and Analytic Chemistry, Academy of Sciences, U. S. S. R., the Carboniferous-Permian boundary corresponds to a figure of 300 million years; the Carboniferous-Devonian, 380 million years; the Devonian-Silurian, 430 million years, i. e., 30 to 60 million years older than shown in the scale below.

The abundance of factual material makes it impossible to give anything like a comprehensive evaluation of the geologic and analytical data used in compiling the scale. For this reason, only a list of key points for the post-Cambrian portion of the 1960 scale is given, with geologic dating and the absolute-age figures as supplied by local laboratories.

As a basis for key points, the Commission adopted data submitted for consideration at the session, on the age determination of biotite and sometimes of muscovite from extrusive rocks (granitoids) with the most pronounced upper or lower boundary. In view of the difficulties in determining the geologic age of intrusive rocks for which only one age boundary is known, or lower, the session also considered and adopted the data obtained on glauconite. Glauconite selected for that purpose came from different regions and from horizons with a definite position in the stratigraphic section, without any visible manifestation of superimposed metamorphic processes.

With regard to the Precambrian portion of the scale, the commission deems it advisable, for the time being, to adopt only the fourfold divisions of the Precambrian, preserving the familiar names. Used in this classification were numerous determinations made in the Radium Institute Academy of Sciences, U. S. S. R., the Precambrian Geology Laboratory Academy of Sciences, U. S. S. R., the Institute of Geochemistry and Analytic Chemistry Academy of Sciences, U. S. S. R., and the All-Union Geological Institute at the Ministry of Geology and Mineral Conservation. The final decision on the names for these major divisions belongs to the Interdepartmental Stratigraphic Commission.

Given in Table 2 is a scale with the absolute-age data for the boundaries between geologic periods, epochs, etc., arrived at from figures in Table 1.

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[1]Geokhronologicheskaya skhala v absolyutnom letoischislenii po dannym laboratorii S. S. S. R. na 1960 g.

Table 1

Figures adopted as a base for the Paleozoic, Mesozoic, and Cenozoic portion of the 1960 absolute-age scale; determination by the K-Ar method, with constants: $\lambda_K = 5.57 \times 10^{-11} year^{-1}$, $\lambda_\beta = 4.72 \times 10^{-10}$ year

Nos.	Samples	Geologic system	Absolute age million years	Laboratory
1	Biotite from ignimbrite, Nal'chic area, Caucasus	Top of Upper Pliocene (cuts Apsheronian beds; overlain by the Quaternary)	3.7	Institute of Geology and Mineralogy A.S., U.S.S.R. (IGEM)
2	Biotite from alkalic pegmatites of Vakis-Dzhavari, Georgia	Upper Eocene	37	Geol. Inst. A.S., Georgian S.S.R.
3	Biotite from the Tezhsar alkalic massif, also from the Akhavnadzor, Bazum, and other granitoid massifs of Armenia	Upper Eocene to Pre-Oligocene	40	Inst. Geol. Sciences A.S. Armenian S.S.R.
4	Glauconite from Eocene beds in Stalingrad borehole, Ciscaucasus	Eocene	46	All-Union Scientific Research Institute in Geology (VSEGEI)
5	Glauconite, Tassarin formation, Turgai	Middle Eocene	49	"
6	Glauconite; Kodor River, Abkhaziya	Paleocene	53	"
7	Glauconite, Ullu-Chay, Dagestan A.S.S.R.	Top of Cretaceous (Danian)	70	"
8	Glauconite, Lysaya Mt., Saratov	Lower Senonian	78	"
9	Glauconite, Bukan'sk deposit, Kaluga Oblast'	Cenomanian	80	"
10	Glauconite, Bol'shaya Laba River, Caucasus	Albian	100	Geol. Inst. A.S., Georgian S.S.R.
11	Glauconite, Postozha River, North Caucasus	Upper Aptian to Lower Albian	103	
12	Glauconite, Bol'shaya Laba River, Baksan, Caucasus	Aptian	106	VSEGEI
13	Glauconite, Yegor'yevskoye deposit, Moscow Oblast'	Valaginian	125	"
14	Biotite from the Kokhpsk granitoid massif of Armenia	Post-Jurassic to Pre-Cenomanian	127	Inst. Geol. Sc. A.S. Armenian S.S.R.
15	Glauconite, Yegor'yevskoye deposit, Moscow Oblast'	Top of Jurassic	136	VSEGEI
16	Biotite from Khalzansk granitoid massif, Tsagan-Oluyevsk complex, Transbaykaliya	Post-Lower Jurassic (Upper Jurassic?)	143	"
17	Biotite from the Olodondinsk and Dulurguyev granite massifs, Kukul'bey complex, Transbaykaliya	Post-Thoarcian (Upper Jurassic)	146	"
18	Biotite and muscovite from the Tanchan complex, North Korea	Post-Triassic	156	"
19	Biotite from Kelasur granitoid massif, west Georgia	Post-Bajocian (Pre-Lower Cretaceous Bathonian)	167	Geol. Inst. A.S. Georgian S.S.R.
20	Biotite from the Khev granitoid massif, west Georgia	Post-Bajocian — Pre Lower Cretaceous (Bathonian)	170 165	" IGEM A.S., U.S.S.R.
21	Biotite from Gumista River granite, west Georgia	Post-Lower Jurassic (Bathonian?)	174	Geol. Inst. A.S. Georgian S.S.R.
22	Biotite from Zhindo River biotite, Transbaykaliya	Post-Triassic (Lower Jurassic?)	180	VSEGEI
23	Biotite from the Kyrinsk granitoids, Transbaykaliya	Post-Permian (Triassic?)	190	"
24	Biotite from quartz diorite, Mt. Yatyrgvart, north Caucasus	Pre-Middle Triassic	200	Geochemistry Institute (GEOKhI) A.S., U.S.S.R.
25	Biotite, Dakhov massif, Caucasus	Pre-Triassic	190	"
26	Biotite from Khosan granitoids, north Caucasus	Post-Upper Paleozoic (Triassic?)	208	VSEGEI
27	Glauconite, North Timan and Indiga Rivers	Lower Permian	274	"

Table 1 (continued)

Nos.	Samples	Geologic system	Absolute age million years	Laboratory
28	Biotite from anorthoclase granite porphyry of the Teniz-Kurzhunkul trough, Central Kazakhstan	Post-Lower Permian (Lower-Middle Triassic)	250-255	Inst. Geol. Sc. Kazakh S.S.R.
29	Zinnwaldite from Erzgebirge Mts. Saxony	Post-Lower Permian	260	GEOKhI
30	Micas from granite massif, South Urals	Post-Lower Carboniferous (Pre-Permian?)	272-288	Bashkirian Affil. A.S., U.S.S.R.
31	Glauconite, village of Dergunovka, Russian platform	Middle Carboniferous	308	VSEGEI
32	Glauconite, village of Lezhen'ka, Borehole No. 38, Novyy Oskol	Upper Devonian	334	"
33	Biotite and muscovite from granite and syenite massifs, Middle and South Urals	Post-Lower Carboniferous	315	Uralian Affil. A.S., U.S.S.R.
34	Biotite from granosyenite and phyllite in contact with pyrite of Urup deposit, north Caucasus	Middle Devonian	340	IGEM A.S., U.S.S.R.
35	Muscovite from pegmatite, Malaya Laba River, north Caucasus	Devonian	240	Lab. Geol. Precambrian A.S., U.S.S.R.
36	Biotite from aplite, Moshchevaya River, north Caucasus	Devonian	345	Daghestan Affil. A.S., U.S.S.R.
37	Biotite from kersantite; muscovite and sericite from metamorphic schist, middle Urals	Post-Middle Devonian	350	Uralian Affil. A.S., U.S.S.R.
38	Micas from crystalline schist of Urushten complex, north Caucasus	Upper Silurian to Lower Devonian	350	IGEM A.S., U.S.S.R. Baghestan Affil. A.S., U.S.S.R.
39	Phlogopite from serpentine of contact-metamorphic granite, Moshchevaya River, north Caucasus	Top of Silurian to Devonian	360	"
40	Mica from granitoids of the Eibenstock, Kirchberg, central Bohemian, and other massifs of Saxony and Czechoslovakia	Post-Devonian (Post-Lower Carboniferous?)	350	GEOKhI
41	Biotite and muscovite from Marininsk-Andreyevsk intrusion, south Urals	Pre-Middle Devonian	370-385	Bashkirian Affil. A.S., U.S.S.R.
42	Sericite from Sibay pyrite deposit, Urals	Post-Eiffelian (Pre-Upper Devonian)	370	Uralian Affil. A.S., U.S.S.R.
43	Biotite and phlogopite from the Tagil-Kushvin syenite massifs, south Urals	Post-Upper Ludlowian	380	"
44	Biotite from Zerendin, Borovsk, Zolotonoshensk massifs, north Kazakhstan	Upper Silurian to Lower Devonian (?)	400-480	Radium Inst. A.S., U.S.S.R.
45	Biotite from the Oninsk intrusion diorite, west Sayan	Post-Wenlock (Pre-Upper Silurian)	413	VSEGEI
46	Mica from Brnovsk massif, Czechoslovakia	Pre-Devonian	430	GEOKhI A.S., U.S.S.R.
47	Muscovite from Urumonguy complex, Transbaykaliya	Post-Middle Cambrian	440	VSEGEI
48	Glauconite, Tosno River, Leningrad Oblast'	Top of Lower Ordovician	450	"
49	Syngenetic biotite from micaceous graptolitic slates, south Urals	Ordovician, Arenigian stage	450	Uralian Affil. A.S., U.S.S.R.
50	Glauconite from borehole No. 2, 175 m, village of Kur, B.S.S.R.	Lower Ordovician	460	VSEGEI
51	Glauconite from Tallin horizon, Esthonia	Top of Lower to base of Middle Ordovician	467	Geol. Inst. Georgian S.S.R.
52	Glauconite from Maarou deposit, Esthonia	"		"
53	Micas from the Aktas, Sarykol, and other intrusives, E. Kazakhstan	Pre-Coblenz — Post-Ludlow (?)	470 (445-500)	Inst. Geol. Sc. A.S. Kazakh S.S.R.
54	Biotite with amphibolite from Kryk-Kuduk massif, North Kazakhstan	Ordovician	500	Radium Inst. A.S., U.S.S.R.
55	Micas from Taniuol complex, Tuva	Post-Lower Cambrian	500	VSEGEI

GEOCHRONOLOGIC AGE SCALE FROM USSR DATA 1960

Table 1 (continued)

Nos.	Samples	Geologic system	Absolute age million years	Laboratory
56	Glauconite from Mantou formation, China	Lower Cambrian	516	VSEGEI
57	Biotite from Martaiginsk syenite-diorite complex, east slope of Kuznetsk Alatau	Post-Lower Cambrian	566	"
58	Glauconite from blue shales, Leningrad	Lower Cambrian	540	Radium Inst. A.S., U.S.S.R.

Table 2

Geochronologic Scale from Absolute-Age Determination Data of 1960

Eras	Periods, epochs			Age in million years, for boundaries of periods, epochs, etc.
Cenozoic	Tertiary	Neogene	Pliocene	10
			Miocene	25
		Paleogene	Oligocene	40
			Eocene	
			Paleocene	70
Mesozoic	Cretaceous		Upper	100
			Lower	140
	Jurassic			185
	Triassic			225
Paleozoic	Permian			270
	Carboniferous			320
	Devonian			400
	Silurian (Gothlandian)			420
	Ordovician			480
	Cambrian			570
Precambrian IV	(Rhyphean, Sinian, Late Precambrian, Proterozoic II)			1100—1200
" III	(Proterozoic, Proterozoic I)			1800—1900
" II	(Archaean)			2600—2700
" I	(Katarchaean)			3400—3500

The source material for the 1960 geochronologic scale have been partly published; the balance is being published in the Proceedings of the Ninth Session of the Commission and in periodicals.

Commission on Absolute-Age Determination of
Geologic Formations, Section of
Geologic-Geographic Sciences,
Academy of Sciences,
U. S. S. R.

SOME CURRENT TRENDS IN THE FIELD OF GEOLOGY OF ORE DEPOSITS IN FRANCE[1]

by

P. Routhier

FOREWORD

We salute this opportunity for a publication exchange with our Soviet colleagues.

At the present time, scientific works appear in many languages; this not only brings up linguistic difficulties but creates an extremely diversified terminology, as well. Carried too far, it may become a dialogue of the deaf, unless measures are taken to define the meaning of the terms used.

On the other hand, no matter how erudite the authors, and no matter how sincere is our desire to internationalize the science, the scientific output will usually betray its national origin. Thus, a slightly experienced French reader, without even knowing the author's name, is likely to tell a translated Russian paper from an Anglo-Saxon one.

Differences in style reflect differences in the thinking process, deeply rooted in the history of nations and in their intellectual development. We shall make no attempt to analyze these differences; we simply state them. It is just as well, of course, that students preserve their national features; however, it would be too bad if these features got in the way of mutual understanding.

In this connection, it is unfortunately true that sessions of the International Geological Congress have become a veritable "Babel of Tongues", to such an extent that they no longer fulfill the main purpose of the Congress. The abundance of material of local interest, presented in the sessions, even if organized by sections, has become a calamity. The Congress should operate only in symposia carefully organized by editorial boards and sufficiently broad to accomodate an expression of all trends.

Until the time when a majority of geologists will have recognized the truth of the above statement (and let us hope that this happens before the closing of the Congress!), partial efforts in that direction are very helpful. There are at least two ways to go about it: either to study a problem through a maximum use of an international bibliography, or to get acquainted with the development of ideas in a given field in one nation, and to emphasize its traits common to other nations.

The second way appears to be the proper one to be used in the exchange between Izvestiya and the Société Géologique de France. We shall try to set forth in this article certain trends discernible in France in the field of the geology of ore deposits, and to compare them, whenever possible, with the schools of thought on the same subject in other countries.

We say, "the geology of ore deposits", in order to underscore the equivocal nature of this expression. The term, "metallogeny", means the totality of our concepts on the origin of ore deposits; its equivocality arises from the fact that it is often used mostly in its physiochemical sense. The term "depositology" (Fr., gîtologie), although etymologically incorrect, would be preferable; however, this would require the use of clumsy prefixes.

MAIN TRENDS OF STUDY

There are very few French works in this field because there are few specialists steadily engaged in this work (only a few tens); the number of mines and mining areas operative in metropolitan France and in the French Union, too, is much smaller than in the U. S. S. R. and U. S. At this point, we feel justified in stating, without being overly chauvinistic, that French works are valuable because of their clarity, the

[1]Nekotoryye sovremennyye napravleniya vo Frantsii v oblasti geologii rudnykh mestorozhdeniy.

[2]Pierre Routhier, Quelques orientation actuelles en France, de la Géologie des gîtes métallifères.

An exchange paper between Bulletin de Societé Géologique de France and Izvestiya of the Academy of Sciences, U.S.S.R., Geologic Series. Soviet geologists will find some interesting, although to some extent controversial, views of the author on the theory of ore deposits. Russian Editorial Board.

strength of their ideas, and the great care used in their argumentation.

A small group of our authors believes that, prior to the formulation of any theory of origin, it is necessary to describe the facts, as fully and precisely as possible, then to compare them as is done in comparative anatomy and physiology. Comparison is the first and cardinal stage of any generalization. There can be no complete genetic theory unless based on physical and chemical facts known from earlier generalizations, however broad they might be. To apply ready-made genetic theories, long since worked out, is like fitting an adult to child's clothes; to reshape a genetic theory to accommodate a single ore deposit or a small number of deposits is like mending a dress with assorted patches.

Are we wrong in saying that, contrary to prevailing illusions, a considerable number of ore deposits have been described poorly and inadequately? To be sure, the deposit itself may be described fairly well; however, this is not always true for the geologic description of its "shell"; the latter is represented, if at all, on different scales, from a regional scale of 1:100, 000 or 1:50, 000 to the 1:500 scale of ore areas. Only a comparison of ore deposits with their natural environment can reveal the "functional relationship" between them, i. e., can suggest criteria in the search for other prospects.

French literature on the geology of ore deposits has concentrated in recent years on a few major problems, namely 1) the role of sedimentation in ore concentration; 2) identification of types of deposits; 3) geology of uranium; and 4) synthesis of minerals to explain the origin of their deposits.

It is impossible to do justice to this subject in a magazine article without scattering one's fire; accordingly, we confine our exposition to these four major problems. In dealing with each one, we shall restrict ourselves to conveying concepts and principal results rather than to describing the details and listing all the arguments. Our Soviet readers will find here but an "introduction" to those investigations which frequently are similar to their own.

ROLE OF SEDIMENTATION IN ORE CONCENTRATION

It is well known that we are far from unanimous on the problem of origin of sulfide ores, primarily bedded types, often found in sedimentary formations, and specifically those occurring not far above the base level of erosion. We designate them here as mantle deposits, although this term is not quite adequate because it is applied also to deposits whose sedimentary origin is indisputable (iron and manganese). These are "telethermal" (L. Greyton, 1933) or "telemagmatic" (P. Niggli, 1941), or "regenerated" deposits (H. Schneiderchen, 1952, and other authors).

The rather vague notions defined by these terms become more and more specific with the progress of paleogeographic and sedimentologic studies.

SEDIMENTATION AND SYNGENETIC CONCENTRATION

Several ore deposits have been studied quite well in recent years, in France and in her territories where French geologists work. One such deposit is the Malines (the Gard Department).

In the period between 1885 and 1950, the Malines lead-zinc deposit yielded 415, 000 metric tons of metal. Although this deposit is not a major commercial one, of the Touisit-Bou Beker blanket type, it may serve as an illustration of such deposits.

The works of F. Foglierini and A. Bernard in Malines have shown that Triassic deposition, particularly that of dolomitic marl and Hettangian dolomite, was followed by an uplift which lasted from the Sinemurian through Bajocian (Figures 1 and 2). Bathonian deposits rest with an angular unconformity either on Hettangian or on Triassic deposits. The thickness of Hettangian deposits is variable, decreasing in the mining area from 210 to 88 m. The Upper Triassic, which generally carries two ore beds, exhibits variations in both thickness and lithology: in the mining area, black bituminous dolomitic marbles thicken along the strike and change to motley marls with evaporites.

These facts show that, beginning with the Triassic, an uplift of the Paleozoic basement (Lower Cambrian dolomites), the Malines "dome", disturbed the Hercinian peneplain. The mineralization proceeded in conformity with the dome's shape and the lithologic and stratigraphic variations emphasizing its outline. The present-day mining is done in the immediate vicinity of the apex of the dome and on its eastern slope; the beds do not come to the very top, everywhere. We pass by the complicated problem of stocks in the stratigraphic units, which send rapidly wedging-out "roots" into the Paleozoic basement; this topic is considered in the A. Bernard dissertation.

On the other hand, mineralographic study by that author has established that the polygenetic Triassic breccia includes fragments of ore characteristic of one of the ore beds. The mineralization took place in Triassic time, as did

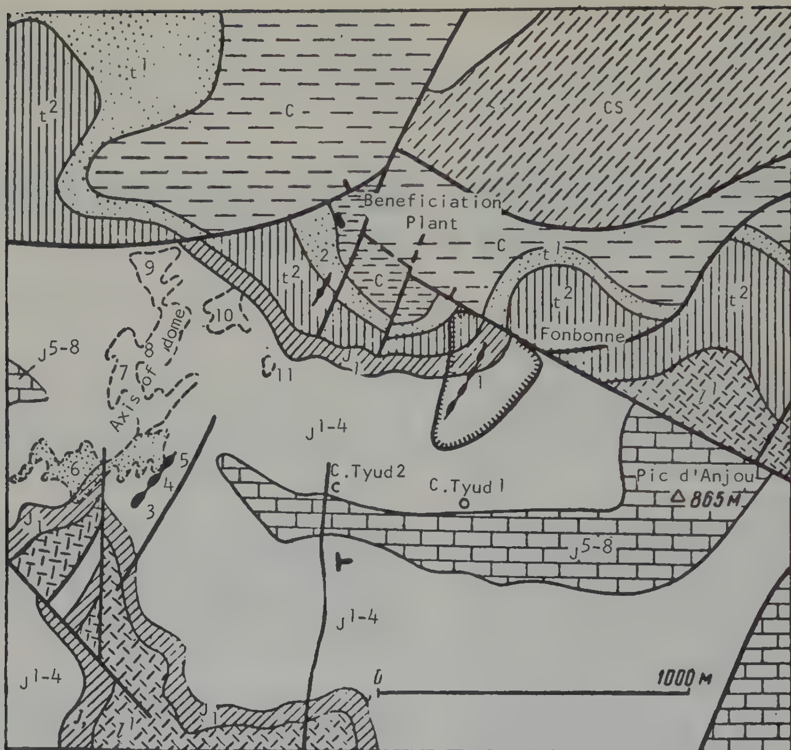

FIGURE 1. Geologic map of Malines (Gard). Compiled chiefly from surveying data of F. Foglierini and A. Bernard [1, 2] and a geologic map kindly put at our disposal by F. Foglierini and S.M.M. Pennaroya.

J^{5-8} - Sequanian, Kimmeridgian, Portlandian, more or less dolomitic; J^{1-4} - Callovian-Rauarcian stage, lithographic limestones with thin intercalations of marl; J_1 - Upper Bathonian dolomite; l^1 - Hettangian "cuboid" dolomite, missing underneath Bathonian deposits in the vicinity of intersecting Malines faults; t^2 - Upper Triassic (Keuper) dolomite, black dolomitic marble, and motley gypsiferous marl; t^1 - Lower and Middle Triassic gray dolomite with a basal conglomerate; C - Lower Cambrian (Georgian) basement; dolomite; CS - Cambro-Silurian schist; solid line, faults and other abnormal contacts; C Tyud - boreholes. Position of the dome axis is approximate. The main exploration zone in the stratified ore body is tentatively marked by a serrate line; obviously, it is located in the southeast limb of the dome.

Mineralization in stocks: a - stocks now being mined in Triassic conglomerates and in the basement under the marls; black, worked out stocks; b - stocks under marls (in Bathonian deposits), with their outlines indicated by a broken line; c - stocks under marls, dotted areas. All stocks have a Cévennes strike, from northeast to southwest.

Stock names: 1 - Petralba; 2 - Castelnaut; 3 - Jean-Vendôme; 4 - Pardalle-Tabuse; 5 - Joseph. The Old Mine area. 6 - Fernan; 7 - South Carbière; 8 - North Carbière; 9 - André; 10 - Tunnel; 11 - Balme (see also cross-section in Figure 3).

Figure 1, along with the other illustrations, has been borrowed from a forthcoming publication by the Masson Press, kindly put at our disposal by the authors.

the reworking of ores; this proves their age differs little from that of the lateral rocks.

The result obtained in Malines can be generalized to at least the marginal zone of the Cévennes, the southern part of a basement structure known as the Central Massif of France. The works of A. Bernard and F. Foglierini in the eastern part of the Cévennes marginal zone, as well as of young investigators from the Laboratoire de Géologie Appliquée, in Paris, in the southern part of that zone, show that all stratified deposits in the marginal zone, irrespective of the age of their component rocks, closely coincide either with stratigraphic breaks or with series of reduced thickness, in other words, with a "wedging out" of sedimentary series. These "wedgings out" are located on

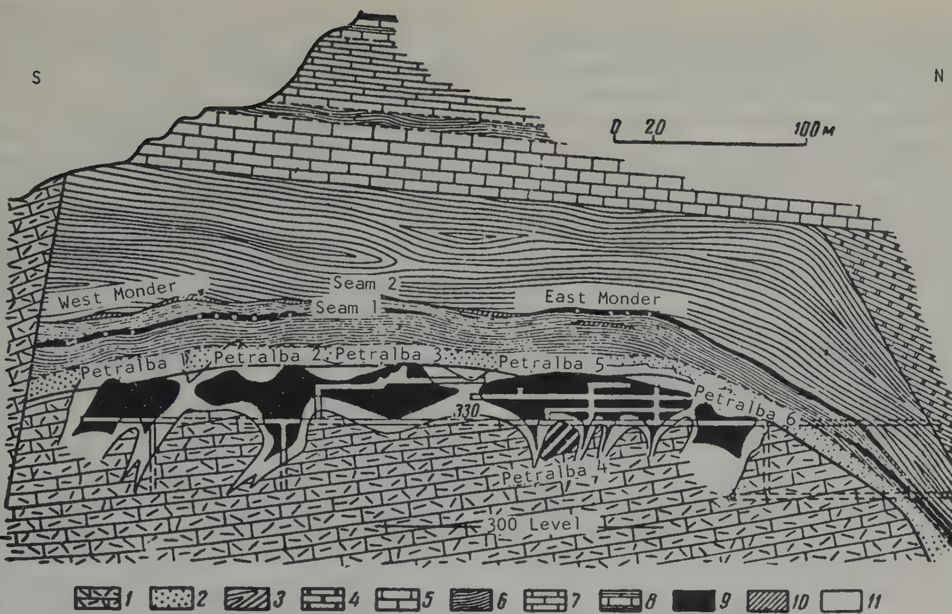

FIGURE 2. The Malines (Gard) lead-zinc ore deposit. The Alba-Fonbonne area. The N - S cross-section shows Petralba horizons and stocks with pointed apophyses in the Paleozoic basement. After S.M.S. Pennaroya.

1 - Cambro-Silurian dolomite; 2 - Triassic conglomerate; 3 - Triassic marl and dolomite; Jurassic deposits; 4 - Hettangian; 5 - Bathonian; 6 - Argovian; 7 - Rauarcian; 8 - Sequanian; 9 - ores explored and in production; 10 - lean and prospective ores; 11 - barite.

uplifts in the Paleozoic basement, similar to "buried hills" discussed in petroleum geology, with mineralization developed chiefly on their slopes.

The role of the Tertiary faults is quite minor. They reflect only later shifts in zones of earlier deformations. In some places the products of an earlier mineralization are deformed; this, however, we cannot duscuss in this brief survey.

The combination of a submarine slope, on which the sediments were shifted and the breccias formed, and the mineralization process was demonstrated quite convincingly by Ph. Launey and R. Leenhardt [15] for the Fijac deposit (Lot). In this, the southwestern marginal zone of the Central Massif, the Sinemurian continental flexure was apparent.

Between the Lower and Upper Sinemurian, this morphology of the sea bottom lost its identity, as did the differentiation of facies and the intensity of the sediment sliding. Thus the zinc mineralization was concentrated essentially either in the breccias or in soft, plicated incompetent beds at the foot of the Lower Sinemurian slope.

It can be stated in the light of this, and from examples assigned in the literature to juvenile hydrothermal formations in their most conservative classical form, that they are similar to the examples cited here. Thus, in the southeastern part of the Missouri area, sandy dolomites contain a "ring" of lead (ore) which caps and surrounds a knob of granite basement [21]; here, we deal with the same phenomena.

Let us consider critically all these examples, not merely structurally but also paleogeomorphically, or rather paleobathimetrically. This leads to the conclusion that some graphic methods of petroleum geology, such as isobath and isopach maps, can be used in the geology of ore deposits, as well (this is clear in the examples of Fijac and southwestern Missouri). Undoubtedly, the time is near when simple means of graphic representations and corresponding generalizations will become means of forecasting in the search for buried mineralization.

We do not claim, of course, that the data cited are unique. However, such data, quite well determined for deposits of oölitic iron and manganese ores as well as for the "Kupferschliefer" type ore deposits, are often neglected in the study of major lead-zinc deposits of a stratified type; this is true for classical works and manuals, not excepting the P. M. Tatarinov book.

All doubts as to the truth of this statement

disappear when we consider that some deposits, such as copper (and cobalt) in Northern Rhodesia, have been found to carry a mineral and chemical zonation [10] determined by the sedimentation process and by paleogeographic conditions, and having originated simultaneously with the formation of sedimentary facies, corresponding to the ancient shoreline. The practice of looking for simple concepts of a conventional magmatic source in every example of exploration for ore bodies is outdated practice; it would hamper exploration.

This author has been developing these views for six years of his teaching career. They originated first during a study of manganese deposits in southern France; the prevailing opinion was that these deposits were juvenile hydrothermal. A controversy arose on this subject, into which we shall not go here, and which would amaze most of our Soviet readers who are quite familiar with the problem of manganese [13].

shows that the products of a lead-zinc mineralization, originally Triassic, have migrated to younger formations [19].

This transfer was effected mostly in connection with a diapir Triassic uplift, as a result of which the mineralization became associated with beds above Upper Cretaceous limestones and Lower Eocene marls and "flowed" into a "Pontian" lake (the age is approximate, Figure 3). A. Moisseeff was able to trace the genetic or rather the phylogenetic sequence of the mineralization process. This sequence of the concentration stages is especially well demonstrated in "lenticular" limestones at the base of the fluvial-lacustrine "Pontian" (Figure 4). These limestones carry various forms of galena concentrations: a) dispersed and syngenetic; b) small "sprays of ooze", undoubtedly injected into a limestone crust, already cemented and consequently somewhat younger although prior to the diagenesis (cementation, lithification);

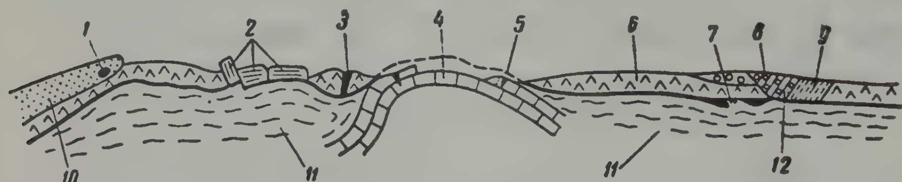

FIGURE 3. Generalized cross-section showing the stratigraphy and structure in Northern Tunisia; after A. Moisseeff [19].

1 - Bou-Djeblah; 2 - Eocene marly limestone; 3 - Bazina; 4 - Campanian limestone; 5 - Djebel El Grefa; 6 - Triassic mantle; 7 - Bou-Dinah; 8 - Djalta; 9 - a "screen" of Pontian marl; 10 - Oligocene sandy flysch; 11 - Lower Eocene marl (Cretaceous-Eocene transition); 12 - Pontian mineralized conglomerate, sandstone, and sandy marl.

My own views were strengthened by the doubts which became more and more apparent in the foreign literature and in the works of my students. Having become, along with other investigators, an advocate of the comprehensive method of ore-deposit study, which does not overlook the study of sedimentation and paleogeography in favor of the paramount structural factor (tectonics), I have realized the necessity of a clean-cut definition for the types of deposits, as we shall see below.

This means that we must beware of dogmatism: on one hand, many problems originate in connection with syngenesis, especially in geochemistry, with which we do not concern ourselves here; however, it is necessary to recognize the various nuances and transitions from syngenesis to epigenesis.

FROM SYNGENESIS TO EPIGENESIS

The study of several deposits in northern Tunisia, such as the Djalta, El Grefa, and Le Semene, apparently different on the whole,

and c) in small fractures and breaks, post-diagenetic and therefore epigenetic in the broadest sense.[3]

In addition, A. Moisseeff recognizes a continuous and even still active migration of lead in the form of galena deposited in a present-day sulfur spring and stalactites of calcite and galena. We concur with him in that "by being related to ground water, the mineralization is not stable but always changing. Here, metallogeny is connected with paleohydrology."

In a quite different region, in the Nyanga syncline (Equatorial Africa), P. Nicolini noted [20] various copper showings related to consecutive sedimentation stages (Figure 5). There is virtually no doubt that an epigenetic "lateral secretion" of elements and minerals took place here along the fractures, first during a syngenetic stage as dispersed or "masked" and

[3]We are mindful of the fact that Soviet authors use sometimes a somewhat different and more complicated nomenclature.

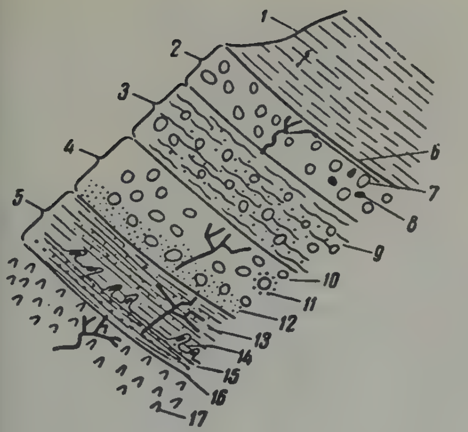

FIGURE 4. Generalized cross-section of lead-zinc mineralization in the Pontian of Northern Tunisia; after A. Moisseeff [19], in the example of Djalta and Bou-Dinah. (El Grefa). Relative thicknesses are not taken into consideration.

1 - upper marl; 2 - bed of red conglomerate; 3 - "Sandy-marl" conglomerate; 4 - "Nougat" conglomerate; 5 - lenticular limestone; 6 - top of the mineralization zone; 7 - barite cerussite veins; 8 - geodes with calcite, galena, and pyrolusite; 9 - mineralized cement; 10 - barite and galena veins; 11 - galena concentration about limestone pebbles; 12 - galena in cement; 13 - diaclases and fractures filled up with epigenetic galena; 14 - "neptunian dikes"; 15 - dispersed syngenetic galena; 16 - vague dolomitization contact, with strontianite at base; 17 - Triassic (source rock).

accompanied by other authigenic minerals (albite, tourmaline); then in the diagenetic stage of "manifest" minerals. This work of P. Nicolini brings to mind the Udokan copper deposits in the Chita Oblast', U. S. S. R. [4], exhibiting, among other things, authigenic minerals in cupriferous sandstone, along with phenomena of epigenetic processing of "stratified" copper in veins.

It appears that these examples lead to two conclusions, as follows:

First is the existence of sulfide concentrations, contemporaneous or nearly so with sedimentation and consequently controlled by its conditions: wedging out near shoals, sliding and brecciation on submarine slopes, etc. Even though the sulfides appear only in the process of diagenesis or lithification of sediments, we shall apply to them the general term, syngenetic concentration.

The second conclusion has to do with hydatogenic concentration, i. e., the one determined by the circulation of aqueous solution of a nonmagmatic origin but borrowing their metals from rocks through which they pass and depositing them in certain "favorite" spots (A. Maucher, 1957). A factor in such migration are connate waters or atmospheric waters which arrived later and were slightly heated at greater depths.

As fractures were formed, these waters moved along them, extracting the metals. Such an epigenetic mineralization, considered from a classical hydrothermal point of view, may proceed both vertically and laterally, depending on the local hydrothermal regime. This migration could have been better understood given a chance for a reconstruction of its paleohydrology, a field of knowledge largely unknown and unquestionably very difficult.

"Juvenile hydrothermalism" does not explain the process of stratified mineralization in a sedimentary mantle; a special discussion has led us to the belief, however, that the "regeneration" version should not be ruled out with regard to the process taking place in veins cutting both the basement and the mantle. Thus a certain contradiction arises; it can be solved only by further study. However, this contradiction does not loom as significant if we consider that there is no radical difference between ascending waters which cool off and descending waters which are rapidly warmed up by the rocks.

As noted by P. M. Tatariniv [33], it has been established in deep drilling for oil that atmospheric waters can penetrate deeply into sedimentary rocks with a great amount of salts where their temperature may reach 100°C. Such waters, by themselves, can be a mineralizing factor; in some places, they may meet ascending magmatic waters, modify their own composition, and bring about a precipitation of elements from solution.

A syngenetic mineralization may be modified hydatogenically to epigenetic, as a result of both the lithologic ("screening") and structural controls. In other words, we have here a true evolution of the mineralizing factor. Such is the meaning of an original term, transformation metallogeny, which fits the general framework of transformism in petrogenesis (K. C. Taupitz, 1954). The main features of this transformation metallogeny, according to A. Bernard's terminology [1, 2], are the soil differentiation (comparable with residual concentrations of iron, nickel, and manganese); sedimentary differentiation; metamorphic differentiation (in some instances); and finally magmatic differentiation. Seen in this light, it becomes clear why metallogenic theories must be supported, as in petrology, by the study of sedimentary rocks. Thus, the science of ore deposits ceases to be a poor

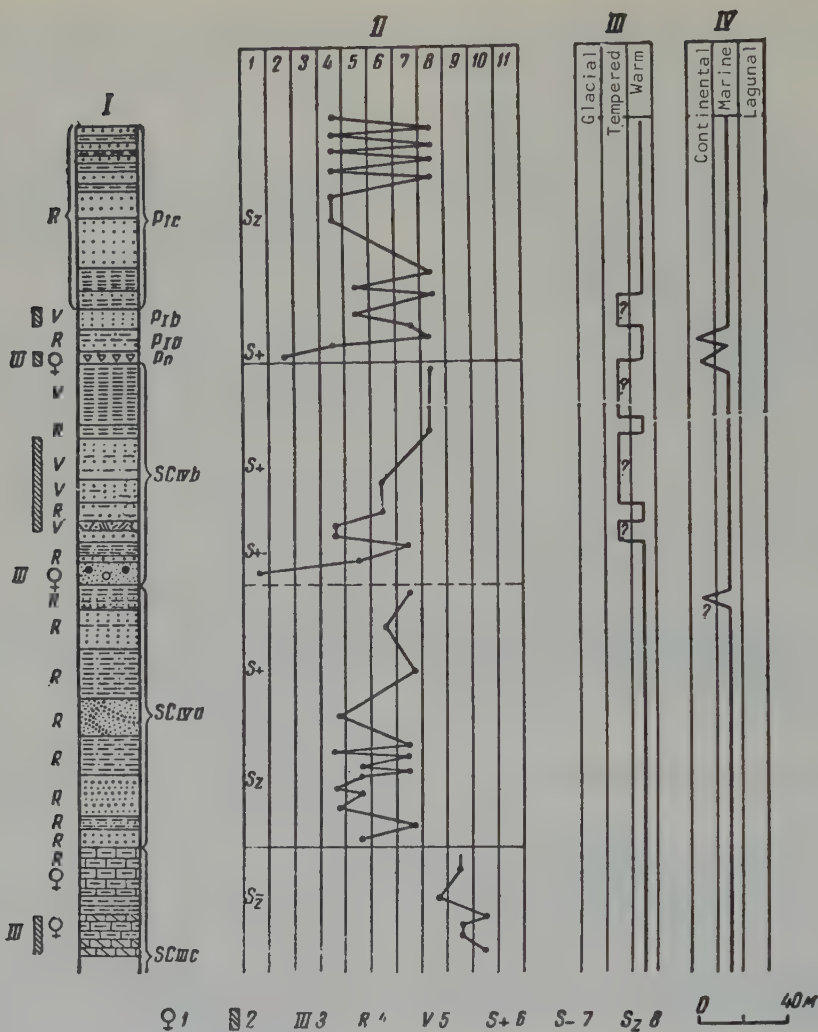

FIGURE 5. Mineralization and sedimentology. An example from a sedimentary series, the Nyanga syncline, Central Congo, presumable Precambrian. Principal stratigraphic intervals are marked with conventional symbols. After P. Nicolini [20].

1 - cupriferous horizon; 2 - pyrite horizon; 3 - authigenic silicates; 4 - red horizon; 5 - green horizon; 6 - upward movements; 7 - downward movements; 8 - alternating movements.

I - Lithostratigraphic column; II - litho-curve by the A. Lombard method [16].

Designations for local standard series (figures in the graph): 1 - conglomerate with either detrital or colloidal cement; 2 - limestone conglomerates; 3 - sandstone, quartzite to coarse arkose; 4 - same, medium-grained; 5 - same, fine-grained; 6 - psammite; shale, micro-sandy to micro-arkosic; 8 - shale; 9 - sandstone to fine-grained calcareous arkose; 10 - calcareous shale and marl; 11 - limestone and dolomitic limestone.

We remind that the "standard" series opens with coarse clastics and changes gradually to clastic rocks — to colloids — colloids mixed with limestones which become gradually purer — to dolomites — and evaporites (evaporites are missing here). Such a sequence corresponds to a transgression. It is represented by ascending litho-curves; the reverse movement is represented by descending curves.

III - Climatic changes; IV - Sedimentary environment.

relation of petrography, confined to a purely descriptive or purely physiochemical content. Invading the field of petrology, it broadens its own scope. It takes advantage of all geologic data, particularly geologic maps of various scales; at this stage of study, it is a substitute for laboratory investigations.

In concluding this chapter, we should like to re-emphasize the necessity for a strong emphasis on the hydrothermal syngenetic-epigenetic phenomena (the deep-seated examples, of course). Such an emphasis, which frequently is a point of agreement for advocates of different concepts, even in the absence of any attempt at their reconciliation, may smooth over many differences in opinion. I believe, however, that even if it does look as though the facts are in favor of "hydrothermalism", it is possible that the future will reveal a connection between hydrothermal synthesis-epigenesis and paleogeography.

THE CONCEPT OF "TYPES" OF DEPOSITS

Inasmuch as careful study has established that the concepts of telethermal, telemagmatic, and regenerated deposits are not immutable and may be even harmful in the course of exploration by distracting geologists from the necessity of a penetrating paleogeographic analysis, the genetic classification should be abandoned and ways found for constructing a new classification, more objective and more practical.

It was on the basis of such considerations that F. Blondel, as early as 1942 [5, 6], and then this author [28, 29] started to define and specify the concept of "type", as given in all classical textbooks, specifically that by L. de Lonney (1923), and as understood in the E. Raguin metallogenic classification [25]. The definition of these "types" should not be based on a genetic concept but rather on the totality of mineral and geologic features observed in the deposits and their "shells". It should be taken into account, to be sure, that some of these characteristic features may have had a different origin; in other words, the convergence phenomena should be considered [26, 27].

There is still much confusion abroad, in defining these types. We had the opportunity to observe just that, in Paris, April 1958, at a meeting of members of the International Subcommission on the Mineral (and Metallogenic) Map. Our Soviet colleagues are more liberal with the use of the term "genetic types" on their maps. F. Blondel, P. Laffit, and myself, became advocates of "mineral-geologic types". This does not mean, however that we refuse to regard "genesis" as a factor sometimes decisively influencing the conclusions of exploration and mining geologists. This does not at all mean that there is no connection between the two series of types; the opposite is true!

We merely believe that the genetic classification groups, on the whole, have been established too hastily, often on sheer intuition, with an inadequate physiochemical basis (particularly for endogenic deposits); it is therefore necessary to return to the analysis of natural phenomena.

CRITICISM OF GENETIC CLASSIFICATIONS

I have already presented an analysis of methodologic errors in genetic classification [29]; this analysis is set forth in more detail, in a forthcoming monograph. Let us refresh our memory on the key points of this criticism.

1. Geologic history of the lateral rocks, as well as their origin, are little known or else inadequately analyzed for many deposits, with some very large ones among them. Take the famous Bushveld lopolith with its deposits of chromite and platinum as an example; there are three ways to explain the intrusion of this complex body: 1) consequent injections; 2) metasomatism of a complex sedimentary body (Van Biljon, 1948); and 3) volcanic sialic-simatic series, more or less recrystallized. How is a deposit to be classified genetically if the petrogenesis of its enclosing rocks is controversial?

2. In most examples, the age relationship between the deposit proper and its "shell" is little known or quite controversial.

This is the argument of syngenesis vs. epigenesis; exogenic vs. endogenic origin of mineralization; the search for a more or less hypothetical "relationship" with magma; and discussion of mostly structural vs. mostly lithologic and stratigraphic critical conditions.

The criteria of dating an ore body with relation to its enclosing rocks, too, are often controversial. When an ore body cuts the structures, it is of course "epigenetic" with respect to them; however, it can be epigenetic even if it is conformable to them. If the data of microscopy suggest that the ores replace the enclosing rock, such replacements should be regarded as subsequent to the original mineralization process. For example, in the Imini deposit group (Morocco) manganese oxides replace the enclosing dolomites. They are often related to transgressive series, as clearly shown in the Chiatur, Nikopol, and other deposits. We should not jump to conclusions on an entire ore deposit on the basis of a few microscopic observations in its marginal zones. Many such replacements are examples of earlier diagenesis and epigenesis.

Radiogeochronologic methods, when applied

without a sufficiently critical approach, as those obtained for uranium deposits in Colorado, Witwatersrand, and Blind River, gave results so contradictory that each of them can be used in the defense of any genetic theory.

In accepting the familiar formula,

$$\frac{206\,Pb}{238\,U} < \frac{207\,Pb}{235\,U} < \frac{207\,Pb}{206\,Pb},$$

and considering the impossibility of its comprehensive explanation at the present level of knowledge, L. R. Stieff and T. W. Stern [32] rightly conclude that experts in radiogeochronology must improve their methods and make more precise the scope of their application before hastily handing to geologists the age figures, thereby forcing upon them hasty genetic concepts. In company with R. Perrin and M. Ronbault [23], I fully share this view.[4]

Under such conditions, it would be quite reasonable not to lose sight of tried-out paleostratigraphic criteria. We have already noted that in connection with the Malines lead-zinc ores.

3. A large number of deposits were formed not at a single stage but rather in a series of concentration stages which may be of a fairly long duration. Herein lies the inherent weakness of genetic classifications of deposits, and this is the point on which I want to make my position perfectly clear.

For example, many copper deposits, such as those named "porphyry copper" by our American colleagues and which are well known in the U. S. S. R., have passed through a hypogenetic hydrothermal phase or, if you would rather have it this way, that of a postmagmatic concentration. This phase developed in the apical parts of plutonic porphyritic monzonites. This was followed by a supergene concentration phase, connected with surface weathering; this concentration phase was much younger than the first one.

The second example is that of iron-ore deposits, the richest among them, everywhere in the world, being connected with ferruginous quartzites. Wherever present, be it the Great Lakes, Brazil, West and Central Africa, the Kursk area, they have passed through a sedimentary concentration phase with the formation of these rhythmic deposits of silica, i. e., iron oxides in ferruginous quartzites. That was followed by local and richer concentrations due to solutions related to metamorphism or rather to continental weathering, which leached out most of the silica, as at Kursk [7].

Thus, depending on personal preference, these deposits can be assigned to either the exogenic-sedimentary or the weathering group, or else to the "metamorphogenic". By the way, the last variant is the least substantiated because even if metamorphism does bring forth some silicates in these deposits, iron oxides and other silicates together with magnetite undoubtedly can be formed during the sedimentary phase (for example, the Lorraine magnetite and many others).

It is clear from the above exposition that the so-called genetic classifications of ore deposits are nothing but classifications of the concentration processes which are active at various stages of the deposit formation. This obvious conclusion is hardly ever considered by "classifiers". Taken by itself, this conclusion expresses the partial inconsistency of genetic classifications of ore deposits. We say, partial, because, in light of what has been said, some deposits have a simple history: a scheelite skarn, for example, generally passes through a single phase of concentration.

It was the inconsistency in genetic classifications that led us to a more "natural" classification, one at the same time better adapted to practical purposes.

MINERAL-GENETIC TYPES

We cannot go into all the details of criteria usable in determining the "types" of mineral deposits or their groups here; this problem is quite complex. Suffice it to say that in selecting such criteria it obviously must be taken into account that some of them, which are observed in the deposit and about it, are an expression of conditions whose combination preceded the formation of that deposit. These are criteria which determine those "functional relationships" which cannot be ignored and whose selection is not always easy! This is the meaning we attribute to the expression, "in the spirit of comparative anatomy and physiology": ore deposits, considered as organisms, have a definite relationship to their environment.

It is the attempt at determining the types of deposits of various metals that leads to bringing together these "functional relationships". F. Blondel was first to identify in this sense about fifteen types of ore deposits. J. Lombard, working from a geochemical point of view, has carried out a similar differentiation for nickel [16], titanium [17], and molybdenum [18]. For my own part, I attempted a systematization of these types and prepared questionnaire cards for each one of them. Thanks to the assistance of

[4]In the Soviet Union, joint investigations are carried on by geologists and radiologists; their objective is not a mere age determination but also a determination of the processes distorting the true ratios of radioactive elements and the products of their decay. Russian Editorial Board.

some of the students at the Laboratoire de Géologie Appliquée, we have about completed a file on the type deposits of manganese, lead-zinc, and uranium.

Given below is a sample card used for the type determination.

Metal. Name of the metal, mineral-geologic so far as possible.

Example: oxide-carbonate oölitic type in transgressive arenaceous series (or the Chiaturi type).

Name of the deposit designated as typical: Chiaturi.

Features of the deposit proper:

I. Hypogenetic paragenesis and, whenever possible, its sequence, either determined or assumed. (It should be kept in mind that the sequence criteria are quite controversial.)

II. Surface weathering of this paragenesis.

III. Chemical composition and the content of hypogene and supergene ores.

IV. Ore reserves, or better yet the amount of metal produced, or metal produced + reserves, or any other numerical data conveying an idea of the economic value of this ore type.

Description of the deposit "shell":

V. Lithology and stratigraphy of the enclosing rock. Contact alterations, if any.

VI. The form of the deposit in relation to the structure of the enclosing rocks.

VII. Adjacent plutonic and volcanic rocks, especially when their presence is believed to have had a considerable effect on the deposit. Zonation phenomena, when present.

VIII. The age of the deposit, whenever possible, which is not often. The dating criteria should be precisely stated; the literature contains many rough approximations and erroneous assertions. A brief geologic history of the area.

These eight points should be set down for a well-known deposit, if possible, i.e., a deposit which may be regarded as a characteristic representative of a "type". If some of the questionnaire points cannot be determined for that deposit, a notation should be made, "In other deposits", or "in such and such an example".

To these eight points, we add the following two:

IX. A list of examples with their ages, as far as possible.

X. Hypothesis on the origin of this type or one deposit of this type.

It goes without saying that this sample card (except for point IX) can be used for individual deposits, as well. A natural progressive way for determining types would be to make up the cards for individual deposits first and then group them by types. However, experience has shown that for expedience a direct type determination is quite possible.

This work is fraught with difficulties. First, there is the obvious lack of uniformity in the published data. Our main source for certain metals are the symposia of the International Geological Congress. We must note here the sad truth that the Twenty-First Session of the Congress discontinued the symposia, although they should constitute the main objective of its work.

The second difficulty, unsurmountable for the time being and a very substantial one, is to fill up the above-mentioned ten points, for all examples. There is no doubt that some, nay many, descriptions of deposits are incomplete and that some geologic maps for the deposit areas are often unsatisfactory; for this reason, their geologic history is fragmentary and their exploration criteria are little known.

FROM TYPES TO "CLASSIFICATION"

After a card has been compiled for a metal or a group of metals, these types are readily grouped into a general scheme whose main divisions are chiefly lithologic. For example, a lead-zinc deposit type may occur in sedimentary rocks without a visible (determined) connection with a plutonic body; the same type may occur also in carbonate, arenaceous, and other rocks, or it may be obviously associated with a plutonic body, being either peri- or intraplutonic, etc. Such features are quite important in practice.

After this has been done for all metals, a scheme for all metals can be compiled (and for all mineral compounds, if necessary, with the exception of mineral fuels). Such a scheme may constitute a "classification", if we so desire, not a genetic classification but rather one which takes into account all genetic factors (physiochemical and geologic). This is a classification built up chiefly with consideration given to the lithologic environment and clearly related to geotectonic conditions. Dolomitic formations with sphalerite, for example, are not deposited under all geotectonic conditions.

Such a classification takes into account "the

environment and the site of origin" but it is unlike the conventional genetic classifications in that it does not arrange deposits by thermal groups.

It is important to note that the path we follow in our methodologic criticism corresponds to practical demands, as it becomes ever more obvious. Thus, Ye. Ye. Zakharov demonstrated for us in the University of Paris (December 1959) his classification scheme which, although ostensibly different from ours, had many similarities to it, in the final account. We both advocate a change in the names for basic subdivisions of a classification, such as endogenic, exogenic, metamorphogenic (especially for the last group which is quite heterogeneous); we do so by virtue of the third conclusion set forth here in pages 22-23).

Such a general scheme and the type schemes for metals will provide an answer, even if a partial one, to two questions posed by mining geologists: 1) what mineral substance should we anticipate under given geologic conditions? and 2) under what geologic conditions are deposits of copper, lead, uranium, etc. to be anticipated?

Thus we arrive at the problem of metallogenic maps and especially metallogenic exploration maps. We note in passing, without developing this topic, that the method of selecting the deposit types is very important in compiling metallogenic maps.

In April 1958, the Soviet delegation in Paris presented very interesting maps and projects based on conventional genetic classifications. The French delegation, on the whole, disagreed with their principles. Our geologists are now working on a map of French deposits, at a scale 1:320,000, which we hope will provide an instructive comparison of the two points of view.

Now, we have considered here the meaning of types in order to demonstrate to our Soviet colleagues that our point of view is not a mere striving for novel constructions but is a result of deliberation on methods and criteria.

SYNTHESES OF MINERALS AND GEOLOGIC THERMOMETERS

Recent investigations in this field in France, however limited in their scope, are nevertheless interesting.

We call attention here to the remarkable syntheses of sulfur compounds obtained by R. Weil [34] at low temperatures of 65 to 100°C in an organic medium, glycerin, in a reaction of salts (chiefly sulfates) and metal oxides with sulfur and cystine. The process was carried out in an aseptic medium (closed tubes). Synthesized in this way were a large number of finely crystalline sulfur-carrying compounds identifiable only by x-ray; present among them are pyrrhotite, pyrite, galena, sphalerite, würtzite, etc. These experiments show a) the possibility of the direct formation of numerous metallic sulfides from organic sulfur; and b) the lack of justification in the often advanced hypothesis of a chemical and biochemical (bacterial) reduction of metal sulfates.

These syntheses are remarkable in that they reveal the great and direct similarity with syngenetic and diagenetic formations of sulfur compounds in sapropelitic and carbonate deposits. They complement the results of the very frequent observations of pyrite, galena, sphalerite, and other compounds in various deposits not affected by the processes of metamorphism and "hydrothermal" action.

Experiments of J. Prouvost [24], mostly unpublished as yet, have demonstrated the possibility of a replacement reaction by electrolysis. They coincide to a certain extent with the K. Schuten experiments (1934, 1940) in which the replacement reactions, especially those of selective replacement, demonstrate the weakness of morphologic criteria in determining the sequence of mineralization stages.

And inasmuch as all problems are interrelated, we are reminded of the V. N. Lodochnikov critical views on the idiomorphism criterion, in his old work (1927), and those of A. Ye. Fersman in "Pegmatites", which also cast a doubt on the correctness of morphologic criteria in determining the sequence of precipitation of ore minerals.

As to geologic thermometry by the liquid inclusions method, G. Deychat alone is consistently working in this field, in France. The most important results of his work have been published in his very interesting monograph (1954).

THE GEOLOGY OF URANIUM

It is known that the search for uranium, carried on intensively and systematically since 1947 in France and throughout the French Union by the Commission à l'Energie Atomique, has been successful, especially in the Massif Central of France, the Vosges, Gabon, Madagascar, etc. The descriptions of uranium deposits have been published by geologists of the Commission; we cite specifically the work on the "Henriette" mine, Crouzille, in the vicinity of Limoges [31], which describes a zone of uraninite mineralization in dimacaceous granite, cut by a lamprophyre vein; also the "Geology of Uranium" by M. Roubot. Along with French deposits, it surveys briefly many foreign deposits.

I am inclined to think that a further development

of this work would be very useful, especially in making geologic maps of the environs of these deposits, as a scale of 1:20,000 or even 1:50,000, in order to bring forth some regularities in the distribution of uranium concentrations. In co-operation with J. P. Gautsch, we have formulated a rule of zonal distribution with relation to plutonic bodies [9].

Because of the lack of space, I cannot develop this idea of mine in this article; I only note in passing that the rejection of simple zonation in the schemes of V. Emmons and A. Ye. Fersman appears to be too arbitrary, coming from these Soviet authors. The presence of "mono-" and "polyascending" zonations does not rule out the presence of some very simple peri- and intra-plutonic zones. For example, in the Massif Central of France, gold-bearing zones encircle dimacaceous granite; the same is true for Gabon. The uranium zone, the presence of which we have suggested for some areas of the Massif Central, may turn out to be of more general significance. Finally, L. Chauris is busy studying the Armorican Massif (Bretagne) zonation which is of great interest.

CONCLUSION

Arriving at the end of this survey, we realize that it is inadequate and that many worthy works have not been mentioned, especially those regional and mineralogic monographs dealing with ore deposits. Omitted, for instance, is a very good and informative work by F. Perminage on the Azegur (Morocco) molybdenum and tungsten deposit which could serve as standard for pyrometasomatic scheelite deposits (skarns and tactites); also the study of M. Weppe [36] on three French tungsten deposits. We regret this omission and we hope we will not be taxed too severely for it. As a compensation, the Moscow Journal of Abstracts, so complete and systematic, along with the bibliography appended to this paper, will supply our Soviet readers with additional material necessary for their guidance.

We reiterate that our main objective is to lay down some basic course in the development of the geology of ore deposits in France and to assist our Soviet colleagues in understanding the general trend of our investigations.

May I indulge in a personal recollection? On one of my trips, a scientist (not from the Soviet Union) said to me, "We do not bother with bibliography because we have learned just about everything in the geology of our country". Such a statement exposes an underestimation of an important fact, to wit: that intellect operates in different ways on similar material. It also exposes an ignorance of the "hologenesis" of scientific thought, that scientific ideas may originate almost simultaneously at different points of the globe. It is therefore essential to know the whereabouts of the scientists who have made discoveries similar to our own, in order to avoid a duplication of work under the conditions of that Babel of Tongues in which we live. (Some duplication obviously is desirable!)

Moreover, we in France are operating with means commensurate with our economic setup. We do not deny, of course, the necessity for numerous measurements, such as geochemical determinations, and we meet this need according to our means. New discoveries and inventions will perhaps be helpful in overcoming some obstacles. The Castaing Sound is now being used in the search for metals. When and if it will have been perfected for minerals, it will serve as a means of rapid determination, which will broaden the scope of our efforts.

Finally, we must mention the cooperation, often a very close one but still inadequately developed, between industrial geologists and those of the "university type". To be sure, many studies, mostly unpublished or not generally known, have been carried out by geologists from State organizations such as the Bureau de Recherches Géologiques et Minières Direction des Mines et de la Géologie de la France d'Outre-Mer, Commission à l'Energie Atomique, and private mining companies.

Whatever the setup in which geologists work, they all pursue the same objectives, by different means and in different fields. Their long range objective is a better understanding for a more successful search, which obviously is the goal for all mining geologists and metallogenists all over the world.

French geologists have discovered considerable iron ore deposits in Africa and other places (Mauritania, French Equatorial Africa); copper deposits (Acjoujt in Mauritania); bauxites (French West and French Equatorial Africa); manganese (Franceville in Gabon); uranium, etc. These discoveries, object demonstrations of human effort and economically profitable, are sometimes criticized in France; we believe, however, that they would amaze our Soviet and American colleagues. This efficiency may be increased. To be sure, at times a closer cooperation between mining and exploration organizations might be desirable; however, this situation is on the mend.

May this brief survey convey to you, our Soviet colleagues, the greetings from your French colleagues who often regret their lack of foreign translations which you have at your disposal. Nevertheless, they are on the alert for your scientific output, and grateful for your striving to learn what is being done abroad. This is reflected in your literature.

Translated from the French by
S. D. Ardashnikova;
Ye. V. Pavlovskiy, Editor

ROSTER OF FRENCH ORGANIZATIONS WORKING IN THE FIELD OF THE GEOLOGY OF ORE DEPOSITS

Mining Bureaus (employing geologists)

Bureau des Recherches géologiques, géophysiques et minières — BRGGM.

Bureau des Recherches d'Outre-Mer — BUMIFOM.

Bureau des Recherches minières d'Algérie.

Bureau minier Guyanais — BMG.

Bureau des Recherches et Participations minières du Maroc — BRPM.

The first four institutions were reorganized in November 1959 into a single Bureau des Récherches Géologiques et Minières (BRGM).

Former Direction des Mines et de la Géologie de la France d'Outre-Mer has completed a regional study and now is being reorganized in connection with the new constitution of the French Union.

Commission de l'Energie Atomique — (CEA).

Universities

Laboratoire de Géologie appliquée.

Ecole Nationale Supérieure de Géologie appliquée et de Prospection minière.

Laboratoire de Géologie.

Laboratoire de Géologie appliquée — Ecole des Mines de Paris.

Ecole des Mines de Nancy.

Institut Catholique de Paris.

This list is incomplete; indicated are only central institutions working regularly in this field.

Chronicle and Translations

La Chronique des Mines d'Outre-Mer et de la Recherche Minière; F. Blondel and J. Lombard, Directors; issues analyses and numerous reports; publishes special issues and folders on current topics.

Le Service d'Information Géologique; J. Roger, Director; formerly a center for paleontologic study and documentation (now reorganized as BRGM); publishes many translations, specifically of Russian works: Fersman, A. Ye., Selected works; Strakhov, N. M., Methods of Study of Sedimentary Rocks; Tatarinov, P. M., the Formation Conditions for Ore and None-Ore Minerals, etc.

Thanks to the Geologic Information Service, French geologists maintain contact with Soviet geologists, at least on most important scientific subjects.

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COMPARATIVE STUDY OF ENDOGENIC MINERALIZATION IN KIMBERLITE FROM THE DALDYN RIVER AND IRON ORE VENTS IN THE ANGRA-ILIM AREA[1]

by

N. V. Pavlov, and I. I. Chuprynina

It is well known that diamond-bearing kimberlite pipes in the Daldyn River area are located in the northeastern marginal part of the Tunguska syneclise, the Siberian platform, and are associated with the Vilyuyka-Kotuy deep fault zone which trends northwest and separates this syneclise from the Anabar anticlise. Fringing the Tunguska syneclise in the west, southwest, and southeast, are two other deep fault zones with columnar bodies of magnetite in the Bakhta River area in the Angara-Noril'sk zone, and from along Nepa River and the Angara-Ilim area, in the Angara-Vilyuy zone.

These authors, in the course of their study of the origin of magnetite deposits in the Siberian platform traprock province, in 1959, visited the Daldyn diamond area in order to study endogenic mineralization in kimberlite.

Two views on the formation of kimberlite have been voiced in our literature in connection with the prospecting, discovery, and exploration of diamond-bearing kimberlite veins. Some students (B. M. Kupletskiy [2, 3]; A. P. Lebedev [5]; A. P. Bobriyevich, G. I. Smirnov, et. al. [2, 3]; V. S. Sobolev [15]) develop the ideas of A. F. Williams, of 1932, to the effect that kimberlite is the crystallization product of an ultrabasic magma [16]. Other authors, L. N. Leont'yev, and A. A. Kadnenskiy [6] and A. A. Menyaylov [7], believe that kimberlites are the differentiation products of a basalt magma and are related in the Siberian platform to traprock volcanism.

Inasmuch as hydrothermal mineralization is the main factor in the discrete evolutionary process of a magmatic melt, manifest after its crystallization at later and terminal stages, the mineral forms of these rocks often exhibit features inherited from the composition of the original magma. We believe, therefore, that a consideration and correlation of hydrothermal mineral formations in the two types of columnar bodies will be a help in solving the problem of the nature of original magmas.

The purpose of our study was to determine general and individual traits for either type of endogenic mineralization and attack the problem of a possible connection between kimberlites and traprock magmatic phenomena in the Siberian platform, or else to verify the assumption of an independent kimberlite magma.

Given below is a comparative analysis of endogenic mineralization in iron ore and kimberlite vents.

Data on the origin of endogenic mineralization for iron-ore deposits related to explosive pipes are added here only for the purposes of our problem; we already have considered this subject in a number of papers, in 1955-1960 [8-14].

ENDOGENIC MINERALIZATION OF IRON-ORE DEPOSITS IN THE ANGARA-ILIM REGION

The numerous ore deposits in the Angara-Ilim region are located at the intersection of two regional deep faults, the Angara-Noril'sk and Angara Vilyuy, also within the latter zone.

In this area, the lower Paleoxoic complex of sedimentary rocks (Upper Cambrian, Ordovician, and Lower Silurian) lies almost horizontally and includes limestone, marl, and shale interbedded with sandstone. These rocks are pierced by explosive pipes filled with basic (dolerite) tuffobreccia and tuff, presumably of Permo-Triassic age. The generally flat-lying position of this sequence has been disturbed by a number of brachyfolds and domes with numerous normal and reverse faults and zones of shattering. These rocks, as well as the columnar breccia bodies, are cut by dolerite sills and dikes (traprock).

The explosive pipes, filled up with tuffs and tuffobreccias, are round, elliptical, to irregular in plan, from several tens of meters to 1 km across. Within the ore field, the pipes are often aligned with the fault and the shattered zone.

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[1]Sravnitel'noye izucheniye endogennoy mineralizatsii kimberlitov r. Daldyn i zhelezorudnykh trubok Angarc-Ilimskogo rayona.

Vertically, they have been traced by drilling down to 600 m; they are sheer columnar bodies, flaring out at top and narrowing down with depth. Near the contacts, horizontal sedimentary beds show a drag effect, with dips reaching 30 to 45°. In the deposit area, dolerite dikes trend mostly sublatitudinally, northeast to northwest, or are located within the pipes and at the contact with the enclosing rocks.

Tuff and tuffobreccia which fill up the pipes consist of fragments of various sizes and compositions, cemented by a fine-grained ash material. The fragments are mostly diabase, metamorphic dolerite, and the enclosing Paleozoic rocks, limestone, dolomite, marl, shale, metashale, and sandstone. The cement of larger fragments consists of small to very fine fragments of the same rocks with an appreciable amount of ash forms such as chloritic glass with spicules of feldspar and pyroxene microlites.

Present both within the pipes and in the enclosing rocks are linearly extended and anastamosing zones of shattering, varying greatly in thickness. These are the zones subject to endogenic mineralization with a precipitation of magnetite ores. The faults also cut the dolerite sills and dikes which, too, are subject to mineralization and ore enrichment.

The mineralization is much less conspicuous outside the zones of shattering. In the pipe tuffs, it is expressed in chloritization and carbonatization; it is practically non-existent in the sedimentary body. In other words, the mineralization is quite definitely associated with tectonic elements which have originated not after the explosive pipes but after the formation of sills and dikes cutting them.

Mineralization zones in the explosive pipes extend from several tens to several hundred meters, with a width of 10 to 400 m. Where the columnar bodies are lined up in a fault zone (Rudnogorsk deposit), the mineralization zone attains 3 km and passes both within them and in the enclosing rocks, as it extends hundreds of meters beyond the pipe. In places, the magnetite mineralization of individual pipes, too, along with the near-ore mineralization, extends beyond the pipes and into lower Paleozoic sedimentary rocks and dolerites about them (the Krasnoyarovsk and Kezhemsk deposits). These ore and mineralization areas do not show any regular distribution of mineral associations, i.e., zonation, except for the regular presence of massive magnetite veins traceable for hundreds of meters and from a few to more than 60 m thick.

The formation of mineralized zones in the explosive pipes proceeded in four consecutive stages. These stages have resulted in the following mineral associations:

Stage One: garnet (grossularite-andradite), diopside, magnomagnetite, apatite, with occasional scapolite and very rare fluorite.

Stage Two: magnomagnetite, apatite, wollastonite, serpentine, chlorite, calcite, zeolites (rare).

Stage Three: calcite, magnomagnetite, hematite, chlorite, sulfides.

Stage Four: quartz (amethyst), chalcedony, calcite.

The first mineralization stage is extremely well expressed in all ore deposits, although its minerals have undergone, in a number of them, considerable metasomatic replacement by minerals of the following stages. Without pausing for a description of these minerals, we only consider their quantitative relationship.

Common minerals are garnet, in places diopside (the Korshunov deposit), magnomagnetite, apatite, serpentine, calcite, chlorite. All other minerals listed above are subordinate. We also note that the principal ore mineral, magnomagnetite, carries 14 to 47% of the magnesioferrite monecule $MgFe_2O_4$ (see Table 1).

Identified by spectrographic analysis among the accessories in ores and mineralized zones were Ti, V, Co, Ni, Cu, Mn, Ga, and occasionally Be.

Thus the endogenic mineralization in columnar bodies of the Angara-Ilim area, filled up with basic tuffobreccia, except for the usual chloritization, is superimposed in conjunction with fault zones and related to "exhalations" from deep-seated hearths of a basalt magma.

ENDOGENIC MINERALIZATION OF KIMBERLITE COLUMNS IN THE DALDYN BASIN

The Daldyn diamond area is located in the Olenek-Vilyuy watershed, the Olenek administrative district, the Yakutian A. S. S. R. The first kimberlite columns were discovered here in 1954; about thirty are known now.

Participating in the structure of this area are lower Paleozoic (Cambrian, Lower Ordovician), carbonates, limestone and dolomite with thin sandy limestone and marl. These rocks are flat, almost horizontal, complicated by minor low brachyanticlinal and brachysynclinal folds, and gentle flexures. Small dolerite dikes are present, with large bodies of dolerites occurring farther west, within the Tunguska syneclise proper. All these structures, as well as the traprock dikes, trend northwest; in a number of places, the dikes trend also northeast and sublatitudinally.

Table 1

Chemical Composition of Magnomagnetites and Magnetites from Iron-Ore Pipes in the Angara-Ilim Region and of the Daldyn Valley Kimberlites (in %)

Magnomagnetites from the Angara-Ilim deposits				Magnetites from diamond-bearing Daldyn vents		
Oxides	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
SiO_2	2.25	2.58	1.16	0.16	0.36	0.50
Al_2O_3	3.80	4.42	3.10	1.2	0.44	1.24
Fe_2O_3	66.22	66.22	70.36	69.10	69.09	67.87
FeO	16.35	17.96	14.10	28.79	28.89	29.27
MnO	—	0.23	0.31	—	—	—
MgO	11.74	6.23	10.03	0.76	0.70	0.83
CaO	—	0.70	0.57	—	0.10	0.22
P_2O_5	—	1.54	0.09	—	—	—
H_2O^+	Not det'd.	Not det'd.	Not det'd.	0.27	0.39	0.36
Total	100.36	101.48	98.31	100.28	99.97	100.29
Elemental molecules in %						
Spinel	8.1	12.5	5.0	3.0	1.0	5.0
Magnesioferrite	44.7	14.1	47.3	0.3	1.0	0.0
Magnetite	47.2	73.4	47.7	96.7	98.0	95.0
Number of atoms in an elemental cell						
Fe^{+3}	14.7	14.0	15.2	15.6	15.8	15.2
Al	1.3	2.0	0.8	0.4	0.2	0.8
Fe^{+2}	3.8	5.9	3.8	7.7	7.8	7.8
Mg	4.2	2.1	4.2	0.3	0.2	0.2

Sample 1: magnomagnetite from the Kezhemsk deposit; Z. Vasil'yeva, Analyst;
Sample 2: magnomagnetite from the Korshunovsk deposit; R. Arest-Yakubovich, Analyst;
Sample 3: magnomagnetite from the Rudnogorsk deposits; V. Chtetsova, Analyst;
Sample 4: magnetite from the Udachnaya vent; V. Nekrasova, Analyst;
Sample 5: magnetite from the Geofizicheskaya vent; V. Nekrasova, Analyst;
Sample 6: magnetite from the Zarnitsa vent; V. Nekrasova, Analyst;
Samples 1, 2, 4-6 were analyzed in the Chemical Laboratory of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Academy of Sciences, U.S.S.R.; sample 3 — at the Chemical Laboratory of the Siberian Geological Trust.

The kimberlite columns are definitely associated with the sublatitudinal faults. For instance, eight columns are lined up along a rectilinear stretch, about 18 km long: the Siberian, Polunochnaya, the twin Udachnaya, Polyarnaya, Festival'naya, Sosednyaya, Daykovaya, and Malyutka; four columns, the Dolgozhdannaya, Geofizicheskaya, Leningradskaya, and Molodezhnaya, are located along a 4.5 km sublatitudinal stretch. Distances between the columns range from a few hundred meters to 5 km.

These kimberlite columns differ in their cross-sections, from rounded (Zarnitza) to rounded-twinned (Udachnaya) and elliptical and oval (Yakutskaya, Akademicheskaya, etc.). Their diameters vary in a broad range, from tens to several hundred meters.

In a vertical section, these columns usually are steep bodies, flaring out at the top and changing to dikes, at depth. The enclosing rocks show a drag effect at the contact with the columns, with dips of 35 to 45% away from them, rapidly becoming flat. Inasmuch as fairly complete descriptions of individual kimberlite columns have already been given [10, 12], we confine ourselves here only to essential and brief information on their material composition, in order to be able to discuss in more detail the features of their hydrothermal mineralization.

Externally, rocks in these kimberlite columns are breccias consisting of fine- to coarse-clastic material of a variable composition and cemented with a gray to green-gray, occasionally greenish-black groundmass.

The bulk of the clastic material consists of fragments of host-carbonate rocks, crystalline schist, gneiss, amphibolite, anorthosite, and other rocks from the lower stage of the Siberian platform, typical of the Anabar and Aldan anticlise, and of fully crystalline ultrabasic rocks — olivinite, peridotite, pyroxenite, eclogite, etc., i. e., deep-seated rocks affiliated with kimberlite and unknown from crystalline ridges of the platform. The fragments are mostly rounded, less commonly sharply angular.

Occurring among clastic material are rounded to fused crystals and sharply angular crystal fragments of olivine, enstatite, diopside, pyrope, ilmenite, and diamond. In most kimberlites, clastic material is present up to 75 or 80%, with only a few of them carrying 20 to 30% and less. The cementing groundmass, if we disregard the subsequent post-igneous alterations, is represented chiefly by finely crystalline olivine and to a considerably smaller extent by monoclinic pyroxene, phlogopite, and possibly by chloritized glass. Two generations of olivine are clearly apparent, in the first approximation: porphyritic aggregates, always rounded (fused, resorbed), 1 to 7 mm and over; and the groundmass olivine with crystalline grains of 0.01 to 0.1 mm and smaller (Figure 1).

kimberlite with phlogopite in the groundmass, visible to the naked eye.

We pause briefly to discuss serpentinization of kimberlite. The Daldyn area kimberlites are strongly serpentinized, both at the surface and down to a depth of 300 to 600 m in boreholes. The groundmass which binds together clastic material and the olivine and pyroxene porphyroblasts are represented by full pseudomorphs of serpentine on olivine, with relicts of the olivine present in very few places. These pseudomorphs, from a few hundredths to one tenth of a millimeter large, are often idiomorphic with relation to chloritized glass and phlogopite of the panidiomorphic granular groundmass. Very characteristically, olivine in porphyritic inclusions, 0.5 to 7 mm (usually 1 to 4 mm), in the presence of complete serpentinization of the groundmass olivine, has been only partially replaced, both at the periphery of the grains and in fissures in them (Figure 5).

Of interest are examples of a partial serpentinization of fine olivine grains in the kimberlite groundmass (see Figure 6), where the serpentine fringe about the grains is joined with serpentine in cleavage fractures within them. Most probably these fissures originated prior

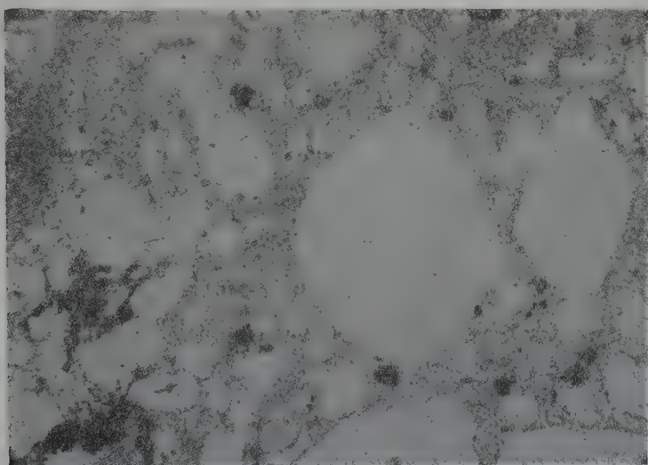

FIGURE 1. Two families of olivine in basaltoid kimberlite.

Olivine grains fully replaced by serpentine. Osennyaya pipe; thin section No. 176; 15 X; single Nicol.

Often visible are veins and veinlets of kimberlite, one to 40 cm thick, cutting the earlier kimberlite (Figure 2); also rounded (ovoid) kimberlite, up to 10 cm in diameter, usually in coarser clastic kimberlite of a quite different texture (Figures 3 and 4).

Among the several varieties, three groups of kimberlites are clearly identifiable: 1) breciated coarse clastic; 2) basaltoid, with a conspicuous groundmass and somewhat subordinate clastic material; and 3) less common basaltoid

to serpentinization, so that serpentine was distributed evenly along the periphery of a grain as well as within it. This suggests that the serpentinization process took place after the rock had been consolidated and was superimposed on it in a migration of mineralizing solutions from some depth.

The serpentine fringes developed along the periphery of porphyritic inclusions of olivine and in fissures within them (Figure 2) compare in thickness with fine olivine grains of the

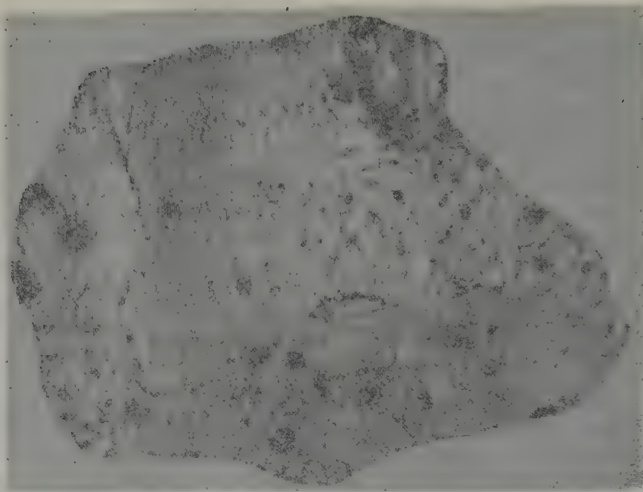

FIGURE 2. Basaltoid kimberlite vein cutting brecciated kimberlite.

Osennyaya pipe; 3/4 natural size.

groundmass; as a rule completely serpentinized. That, too, suggests that the serpentinization is posterior to crystallization of the bulk of kimberlite.

The presence of individual varieties of kimberlite in veins within a single columnar body, along with the presence of rounded inclusions of kimberlite in kimberlite (Figure 3), indicates that the formation process for kimberlite columns occurred in several stages. It appears that each kimberlite magma injection stage was accompanied by new batches of serpentinized solutions, which finally led to a complete serpentinization of both the bulk of the kimberlite and coarse porphyroblasts of olivine and pyroxene. The serpentinization of olivine in kimberlite was accompanied by the formation of dust-like magnetite grains fairly evenly dispersed in the rock. The formation of serpentine and magnetite was accompanied by an intensive carbonatization represented by a fine dispersion of calcite, in both olivine and the vitreous kimberlite body.

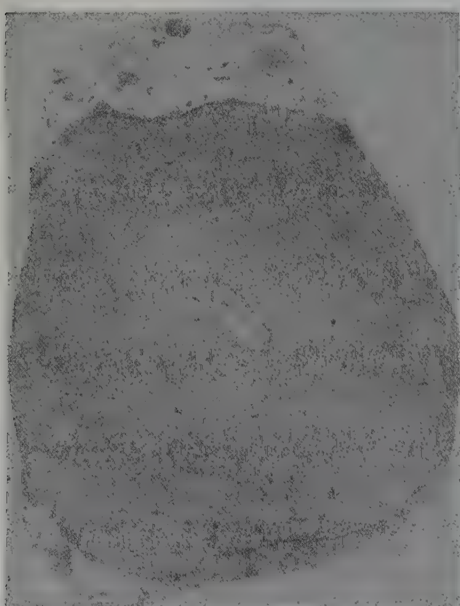

FIGURE 3. Kimberlite in kimberlite.

Zarnitsa pipe; ore specimen No. 140; natural size

The repeated penetration of explosive pipes by kimberlite magma indicates the presence of zones of weakness in them, during an igneous stage, while the nearly total serpentinization of kimberlite suggests that such zones of weakness and fracturing originated at post-igneous stages, as well.

The evidence of post-serpentinization tectonic phenomena in these columnar bodies is found in veins, veinlets, and lenticular to pocket-like bodies filled with hydrothermal minerals cutting the serpentinized kimberlites. As yet, there are no positive data on regularities in the spatial distribution of these formations within the columnar bodies. It can be stated only that they are more common in the zones of shattering and intensive fracturing along the periphery of the columnar bodies than within them. The veins usually are a few decimeters, less commonly meters, long and several centimeters thick. The veinlets form dendritic to parallel series, several tenths of a centimeter long, or even less, and several millimeters to 2 cm thick. The lenses and pockets usually are rather small, measured in centimeters and

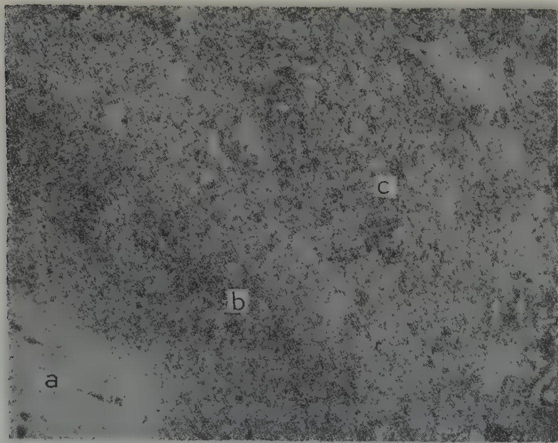

FIGURE 4. Kimberlite in kimberlite.

A rounded olivine-pyrope fragment (a) has a fringe of dark-green, cryptocrystalline kimberlite (b) fringed in turn by a better-crystallized kimberlite (c). This complex body is enclosed in brecciated kimberlite. Zarnitsa pipe/ thin section No. 160; 16 X; single Nicol.

decimeters. The mineralization related to such formations is minor, involving not over 1% of the total kimberlite.

In their mineral composition, these formations are divisible into five groups:

1) veins, veinlets, and pockets of a gel-like serpentine (serpophyte);

2) veins, veinlets, pockets, and lenticular bodies of serpentine magnetite, and calcite (Figure 7);

3) veins and pockets of calcite and sulfides (pyrrhotite, pyrite, chalcopyrite, etc.);

4) veins and pockets of calcite, celestite, strontianite, and barite (Figure 8);

5) veins and pockets of granular calcite.

In addition, kimberlite contains rounded to less commonly angular fragments of carbonate sedimentary rocks, partly to fully replaced by magnetite, serpentine, occasionally by celestite and strontianite (Figure 9). Very

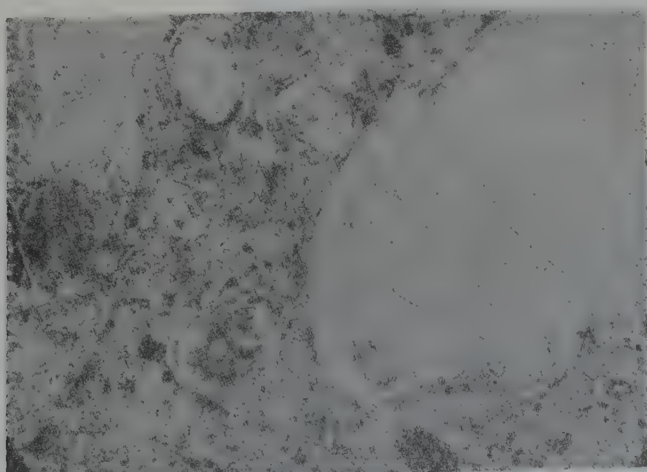

FIGURE 5. Partial replacement of an olivine inclusion by serpentine, and a complete replacement of the groundmass olivine by serpentine.

Udachnaya pipe; thin section No. 42; 35 X; single Nicol.

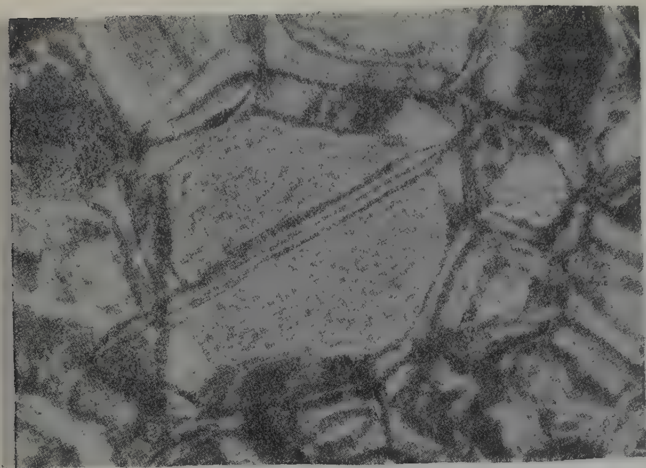

FIGURE 6. Replacement of olivine by serpentine along the grain periphery and in fissures.

Udachanya pipe; thin section No. 42; 270 X; parallel Nicols.

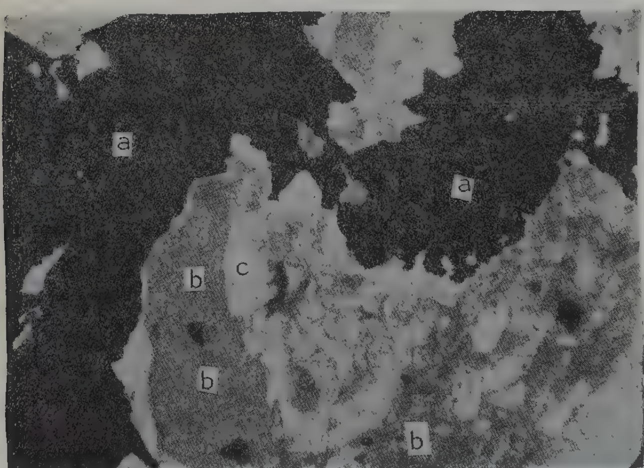

FIGURE 7. Precipitation of magnetite (a), serpentine (b) and calcite (c) in a lens in serpentinized kimberlite.

Udachnaya pipe; thin section No. 52; 35 X; parallel Nicols.

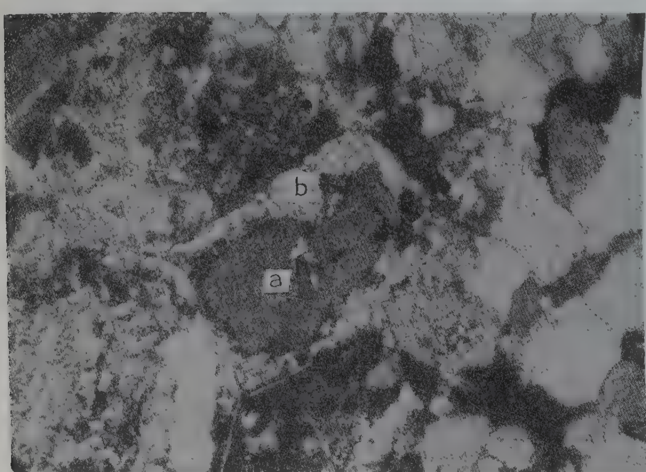

FIGURE 8. Calcite - strontianite - celestite veinlet in kimberlite. Replacement of celestite (a) by strontianite (b).

Udachnaya pipe; thin section No. 7; 35 X; Nicols crossed.

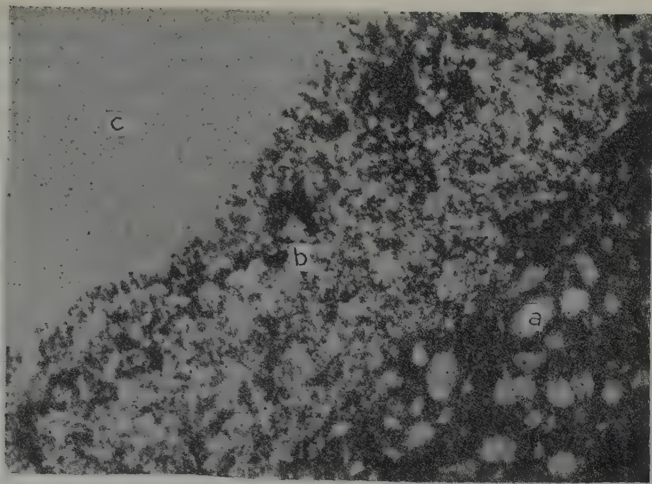

FIGURE 9. Zone of contact between fragments of limestone and kimberlite.

a - kimberlite; b - magnetite with calcite; c - limestone. Malyutka pipe; thin section No. 84; 15 X; single nicol.

characteristically, the form of the original fragment in kimberlite is preserved in this replacement. Carbonate rock fragments are frequently leached out, leaving behind a cavity filled with magnetite, calcite, and serpentine. Also present are cavities filled with calcite, celestite, and strontianite.

These data show that accessory elements which are the most characteristic in hydrothermal minerals related to post-igneous developments in kimberlite are Mn, Ti, Cu, Sr, Ba, and Zn, and to a smaller extent Ni, Co, Pb, Cr, and V (see Table 2).

The following conclusions can be drawn from the above exposition:

1) The intrusion of the kimberlite melt proceeded in pulsations, with even the individual batches entering in several installments corresponding to the formation of weakened zones in the vents; coarse clastic brecciated kimberlite gave place to fine clastic basaltoid kimberlite; judging from the ovoid inclusions of kimberlite in kimberlite, it appears that this process was reversed in several places.

2) The kimberlite melt, formed during the magmatic crystallization proper, underwent post-igneous alterations after its solidification; these alterations brought about a regional serpentinization and carbonatization. It appears that serpentinizing solutions did not accumulate in the interstices of olivine and pyroxene grains, during their crystallization, but came up from some depth. It is possible that these serpentinizing and carbonatizing solutions were also connected with the arrival of new batches of kimberlite melt.

The serpentinization of olivine was accompanied by a liberation from it of ferrous iron, a partial oxidation of the ferrous iron, and the formation of abundant dust-like magnetite, fairly evenly dispersed throughout the rock.

Formed in vents after the regional serpentinization were systems of comparatively thin fractures and hollows filled with hydrothermal minerals.

The earliest hydrothermal formations are lenses and pockets of gel-like serpentine. Closely related to them are veins, pockets, lenses, and veinlets filled, along with the gel serpentine, by magnetite and calcite. Veinlets of calcite with sulfides (pyrrhotite, pyrite, some galena) were formed somewhat later. Among the youngest formations are veinlets, pockets, and lenses of calcite, celestite, strontianite, and barite, or calcite alone.

Typical minor element additions in hydrothermal minerals are Mn, Ti, Cu, Zn, Sr, Ba, and to a smaller extent Cr, Ni, Co, and Pb.

Thus, traceable in the Daldyn area diamond-bearing kimberlite columns is a progressive development of a magmatic stage proper in the formation of a kimberlite melt, followed by post-magmatic processes. The latter were expressed in a regional serpentinization of kimberlite, accompanied by a dust-like dispersion of magnetite and calcite, with minor hydrothermal veins, veinlets, pockets, and lenses forming later stages and filled with serpentine, magnetite, and calcite, with poorly developed sulfide incrustations; and finally with calcite, celestite, barite, and strontianite.

Table 2

Accessory elements in hydrothermal minerals of kimberlite (in %)

Minerals	Mn	Pb	Ga	V	Cu	Zn	Ti	Co	Ni	Cr	Sr	Ba
Serpentine	0.005 —0.05	—	0—0.001	0.0001—0.0005	0.0001—0.007	0—0.01	0.05 —0.1	0—0.1	0.001—0.1	0—0.007	0—0.01	—
Calcite (calcite-strontianite)	0.0007—0.5	—	—	—	0—0.001	—	0.005—0.01	—	0—0.001	—	0.01—5.0	0.01—0.5
Strontianite	0.0001—0.0005	—	—	—	—	—	0.005	—	—	—	>9	0.5
Celestite	0—0.0001	—	—	—	—	—	0.005	—	—	—	>9	0.5 —3.0
Magnetite	0.01—0.5	0—0.005	—	—	0.0005—0.001	0.01—0.07	0.005—0.007	—		—	—	—
Pyrrhotite	0.0005	—	—	—	—	0.1	0.0007	—	0.07	—	—	—

A comparison of features of the hydrothermal mineralization segments and their composition in iron-ore pipes of the Angara-Ilim region with those in the diamond-bearing pipes of the Daldyn area leads to the following conclusions:

1. Conspicuous in iron-ore pipes are zones of shattering which were the sites of an intensive superimposed endogenic mineralization. Hydrothermal solutions which have formed the mineralized and ore zones are related to deep-seated basalt magma hearths.

No such superimposed mineralization zones are present in the diamond-bearing veins. Here, hydrothermal minerals are concentrated in thin veins, lenticular bodies, pockets, and small cavities in serpentinized kimberlite, where they occur in very small amounts.

2. Hydrothermal mineralization in iron-ore pipes is characterized by features different from those in diamond-bearing pipes. Strongly developed in the former were two high-temperature stages marked by the formation of such minerals as garnet, diopside, magnomagnetite, apatite, and others — all totally missing in the second instance. There is somewhat more similarity between the mineral composition of the third and fourth mineralization stages in iron-ore pipes, and that of the earlier hydrothermal formations in diamond-bearing pipes; however, even here there are substantial differences. Thus, precipitated at these stages in iron-ore pipes are calcite, magnomagnetite, hematite, chlorite, sulfides of iron and copper, and quartz (amethyst, and chalcedony), while serpentine, magnetite, calcite, and iron sulfides are deposited in diamond-bearing pipes. In addition, the presence of calcite with celestite, strontianite, and barite, among the later hydrothermal formations is very characteristic of the kimberlite veins, while these minerals are missing in iron-ore pipes. Individual varieties of calcite in iron-ore pipes have a somewhat higher strontium content.

If the hydrothermal formations in iron-ore pipes and kimberlites be compared for their accessory elements, they would reveal some similarity as well as a sharp difference: they both are characterized by an addition of Mn, Ti, Ni, and Cu; on the other hand, although V and Co are present in minerals of both formations, their content of hydrothermal kimberlite minerals is much lower than in minerals of iron-ore pipes; the latter also carry Mo, Ga, and often Be, all three totally missing in hydrothermal minerals of kimberlite pipes. Conversely, such elements as Cr, Sr, and Ba, typical of the kimberlite hydrothermal minerals, are unknown, with the exception of Sr, from hydrothermal minerals of iron-ore pipes.

Finally, it should be noted that magnetite from the kimberlite hydrothermal formations

is quite different from that of iron-ore pipes, in its almost complete lack of magnesium, while the latter may carry as much as 6 or 11% MgO (see Table 1). This suggests that oxidation-reduction conditions for hydrothermal processes in kimberlite pipes were different from those in the formation of ores in iron-ore pipes (A. G. Beteckhtin [1]).

SUMMARY

The Angara-Ilim iron-ore pipes are very similar, structurally and morphologically, to the Daldyn River area diamond-bearing pipes, although they are quite different in composition. The iron-ore pipes are made up of dolerite-basalt breccias, while the diamond-bearing pipes are made up of hypabyssal ultrabasic kimberlite. Endogenic mineralization in the iron-ore pipes is related to deep-seated activity of a basalt (traprock) magma; it has been superimposed on their tuffs. Endogenic mineralization in diamond-bearing pipes is related to the evolution of an ultrabasic magma entering them in pulses and crystallizing. Coming up from the pipe roots were hydrothermal solutions which brought about serpentinization, carbonatization and the formation of hydrothermal veins in now-crystallized kimberlite of the upper and middle segments of these pipes.

The sharply different paragenetic associations of endogenic minerals in iron-ore and diamond-bearing pipes indicate a difference in the composition of their original solutions and in the physiochemical conditions of their mineral precipitation.

All this confirms once more that endogenic mineralization in kimberlite is essentially different from that in columnar bodies related to the dolerite-basalt magma. The speculations of earlier investigators to the effect that kimberlites have no genetic relationship to traprock but are rather the product of crystallization of an independent ultrabasic (kimberlite) magma thus receive additional corroboration.

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Institute of Geology of Ore Deposits,
Petrography, Mineralogy, and Geochemistry,
Academy of Sciences, U. S. S. R., Moscow

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THERMAL CHARACTERISTICS OF MUSCOVITE SAMPLES FROM DIFFERENT ZONES OF A PEGMATITE VEIN[1]

by

K. M. Feodot'yev, and V. A. Khvostova

A study of the separation of water from specimens in different zones in a pegmatite vein, east Sayans, has led to the identification of three groups of muscovite, differing in their temperature of dehydration.

The establishment of different thermal behavior for muscovite of different generations affords the means of using this mineral as an index of the physiochemical conditions for the formation of minerals paragenetically associated with it.

* * * * *

While studying the east Sayans pegmatites exposed at Krasnyy Springs, one of the authors has collected samples of micas from different zones of a pegmatite vein. They were mostly muscovite. Externally, these samples were different, being either coarse tablets or aggregates of fine crystals, occasionally porcelain-like. The mineralogic environment of these muscovite varieties suggested different physiochemical conditions of formation. However, attempts at correlating their external aspect with conditions of formation were unsuccessful. Whether this difference in their conditions of formation was reflected in the structure of micas and, if so, to what extent, had to be determined by a laboratory processing of these samples. This paper deals with some results of our work on muscovite.

The pegmatite body is fringed by an unbroken quartz-tourmaline band consisting of 50% tourmaline and 50% finely crystalline quartz. This fringe runs along the contact between the pegmatite body and the enclosing rocks.

The outer zone of this pegmatite body, the quartz-muscovite band, is considerably thicker (reaching 0.1 m). It consists of 70% finely crystalline quartz and 30% fine-scaled to finely tabular silver-white mica.

The quartz-muscovite zone of the replacing complex is best developed in the floor of the northeastern part of the vein, where it consistently extends along the vein. This zone is made up of bands, irregular inlets, pockets, and splotches. Its thickness is different in different places, ranging from 0.1 to 1.5 m. Its bulk is quartz and muscovite with relicts of microcline almost completely replaced by albite. Also present in the quartz-muscovite replacing complex are some accessory minerals.

A zone of sugary albite and clevelandite makes up most of the vein. Its boundary with the quartz-muscovite zone of the replacing complex is uneven to sinuous. Here, albite accounts for 80 to 85%, with but 10 to 15% of the area taken up by quartz-muscovite pockets or by aggregates of muscovite alone.

Microcline, usually replaced by albite, has been preserved in occasional relicts. Accessory minerals are present besides albite, microcline, and muscovite.

A zone of massive microcline extends along the vein axis, although not everywhere. Where present, it is as much as 1.2 m thick. The entire space between the microcline relicts is filled up with quartz muscovite and albite, with a sizable body of muscovite (3 to 4 cm) observed also with the microcline fragments.

A quartz spodumene zone, in central segments of the vein, carries accumulations of coarsely tabular muscovite.

It appears from this brief description of individual zones in the pegmatite body that

[1]Termicheskaya kharakteristika obraztsov muskovita iz razlichnykh zon pegmatitovoy zhily.

muscovite occurs in different parts of the vein and is morphologically different. Given below is a brief description of muscovite from various parts of the vein.

The formation of muscovite in this pegmatite vein began with the intrusion of a pegmatite melt into the enclosing quartz-biotite schist. Crystals of muscovite in the quartz-muscovite fringe correspond to this first stage of crystallization. Muscovite in the near-wall part of the vein is an aggregate of fine silver-white scales. It appears that this mica has been formed at the pegmatite melt temperature (phase D—E of A.Ye. Fersman).

The next sample of muscovite (specimen No. 44) is from a veinlet in microcline where it is finely crystalline to fine-scaled, green. Also present here is a coarsely crystalline mica forming pockets in microcline (specimen No. 44-a).

A green muscovite was collected from the quartz-microcline rock (specimen Nos. 257 and 3).

Mica from the replacing quartz-muscovite complex is made up of silvery white to greenish tablets, 3 to 4 cm in diameter (speciman No. 38).

Finally, muscovite in paragenesis with albite and formed apparently simultaneously with it, is represented by silvery white to slightly greenish tablets, 0.5 cm across (speciman No. 56).

THE CHEMICAL AND THERMAL CHARACTERISTICS OF MUSCOVITES

These seven samples of muscovite were studied in the laboratory. The relative age characteristics have been determined for some of them from their relationship to other minerals or from their position in the pegmatite body.

Figures in Table 1 give an idea of some features in the chemical composition for the Sayan muscovite samples. Nearly all analyses show a low silica content; this is especially true for the quartz-muscovite fringe sample. That corroborates to a certain extent the J. Jakob data [5], which is more than can be said of other deposits [1].

All mica samples contain a small trace of sodium; those from the contact with the enclosing rocks also carry some calcium. The isomorphic sodium trace is to be anticipated, considering the widely developed albitization typical of the Sayan pegmatites. Calcium has been found only in samples coming from a contact with the enclosing crystalline schist.

The apparent deficiency in alumina is compensated by the presence of iron.

Unfortunately, not all samples were analyzed for fluorine. Those that were carried a very small amount of it.

The determination of the hydoxylion in micas turned out to be quite difficult and inadequate. The water content depends to a very considerable extent on the degree of grinding, as has been noted by earlier investigators [3]. The analyses cited exhibit certain fluctuations but they are quite slight.

J. Jakov [5] based his judgment of the chemistry of muscovite on the alkali-water ratio. We believe that this criterion is not representative, because the water content, as determined by an analysis, is not constant for a given sample; it is affected by many factors which cannot be accounted for (the degree of pulverization of a sample, the air humidity, etc.).

For these reasons, we have adopted a method of dehydration curves, in our study.

Table 2 presents the crystallographic formulas for muscovites under study. The conversion was done by the familiar method, with 12 oxygen atoms assumed in the formula [2].

The dehydration curves were recorded by an automatic weight-loss recorder. The samples were kept at temperatures with an interval of 50°C, automatically maintained, until their weight became constant. Such dehydration curves, close to the isothermal, differ both in their aspect and substance from the latest dynamic weight loss curves [3].

Special attention was paid to the processing of samples for analysis. It has already been noted that the grinding of a mica sample strongly affects it, bringing about a higher water content and a modification of its liberation during heating. With this in mind, we split large samples into thin tablets and cut them with scissors into narrow bands. Finely crystalline samples were not ground but were placed in a crucible, intact. Thus our results from the weight-loss determination (water loss) are fairly accurate.

Table 3 presents dehydration data for the Sayan muscovites. They are reduced to a diagram of dehydration curves in Figure 1.

All micas are divided into three types, by the nature of their dehydration. Some samples begin to lose their water at a temperature of about 800 to 900°C (Table 3). This loss is rapid and takes place with only a small difference between the temperature at the beginning and at the end of dehydration. The second type of muscovite is characterized by a more complicated dehydration curve. It shows the beginning of the

Table 1

Chemical Composition of the Sayan Muscovites

Components	I		II		III		IV		V		VI		VII	
	weight %	molecular weight	weight %	molecular weight	weight %	molecular weight	weight %	molecular weight	weight %	molecular weight	weight %	molecular weight	weight %	molecular weight
SiO_2	42.23	703	44.46	740	45.80	762	45.06	750	45.03	750	43.24	720	45.89	764
TiO_2	0.27	3	—	—	—	—	—	—	0.03	—	0.04	—	—	—
Al_2O_3	38.12	374	37.91	372	37.08	364	38.00	372	38.04	373	38.39	376	37.07	364
Fe_2O_3	0.74	4	1.19	7	0.51	3	0.38	2	1.69	10	1.48	9	0.51	3
FeO	0.63	8	0.23	3	0.56	8	0.68	9	Not det'd.	—	Not det'd.	—	0.57	8
MnO	Trace	—	Trace	—	—	—	—	—	"	—	Trace	—	—	—
CaO	1.24	22	1.26	22	0.40	7	0.06	1	Not det'd.	—	0.19	3	—	—
MgO	1.35	33	0.71	17	0.09	2	0.07	2	"	—	0.37	9	0.08	2
Na_2O	1.90	30	Trace	—	0.85	14	1.03	17	1.41	23	1.39	22	0.95	15
K_2O	9.00	95	11.42	121	10.11	107	10.15	103	8.56	91	9.82	104	10.17	108
H_2O^-	—	—	—	—	—	—	—	—	—	—	—	—	0.08	4
H_2O^+	4.49	250	3.10	172	4.29	238	4.29	238	5.50	305	4.85	269	4.30	239
F	Not det'd.	—	Not det'd.	—	0.16	8	0.34	18		—		—	0.17	9
Total $-O_2=F$	99.97	—	100.28	—	99.87 0.07 99.80	—	100.06 0.14 99.92	—	100.26	—	99.77	—	99.79 —0.07 99.72	—
Analyst	N.N. Korotkova		Z.T. Kitayeva		V.M. Nekrasova				V. Romadova		N.N. Korotkova		V.M. Nekrasova	

I. Sample No. 22: from the quartz-muscovite fringe;
II. Sample No. 44: veinlets in microcline;
III. Sample No. 257: from quartz-microcline rock;
IV. Sample No. 44-a: pockets in microcline;
V. Sample No. 3: from quartz-microcline rock;
VI. Sample No. 38: from a quartz-muscovite complex;
VII. Sample No. 56: from an albite vein intergrown with albite.

Table 2

Crystallochemical Formulas for the Sayan Muscovite

Samples from Table 1	Group K			Group Al				Group Si,O			Group OH, F	
	K	Na	Ca	Al	Fe^{3+}	Mg	Fe^{2+}	Al	Si	O	OH	F
I	0.76;	0.24;	0.09	1.83;	0.03;	0.13;	0.03	1.17;	2.83	10.00	2.00	—
	1.09			2.02				4			2.00	
II	0.98	—	0.09	1.93;	0.05;	0.06;	0.01	1.04;	2.96	10.23	1.77	—
	1.17			2.05				4			1.77	
III	0.85;	0.11;	0.02	1.95;	0.02;	—	0.03	0.95;	3.05	10.08	1.89;	0.03
	0.98			2.00				4			1.92	
IV	0.86;	0.13	—	1.98;	0.02;	0.01;	0.03	1.00;	3.00	10.02	1.91;	0.07
	0.99			2.04				4			1.98	
V	0.71;	0.18	—	1.88;	0.08	—	—	1.05;	2.95	9.75	2.25	—
	0.89			1.96				4			2.25	
VI	0.83;	0.17;	0.01	1.87;	0.07;	0.03	—	1.13;	2.87	9.85	2.15	—
	1.01			1.97				4			2.15	
VII	0.86;	0.12	—	1.93;	0.02	—	0.03	0.96;	3.04	10.04	1.93;	0.03
	0.98			1.98				4			1.96	

water loss in the 600 to 700°C interval, with 0.3 to 0.5% water usually liberated at that temperature. Then there is a horizontal segment, and the further water loss is the same as for standard muscovites. The third type is represented by muscovites carrying readily liberated water. Upon heating, such micas give up about 1% of their water at a temperature of about 110°; this is followed by a state of equilibrium; then the rest of the water begins to escape at a temperature of about 850°C. The dehydration at that stage, as in the other two groups, proceeds in a very narrow temperature range.

Table 3

Dehydration of the Sayan Muscovites (Samples I-VII in Table 1)

I			II			III			IV		
Temperature C°	Weight loss, %	Difference, %	Temperature C°	Weight loss, %	Difference, %	Temp. C°	Weight loss, %	Difference, %	Temp. C°	Weight loss, %	Difference, %
860	0		850	0		790	0		650	0	
870	1.25	1.25	890	2.15	2.15	810	1.83	1.83	660	0.38	0.38
900	4.72	2.47	940	3.60	1.45	920	4.27	2.44	830	0.38	0.00
			980	4.00	0.40				850	4.55	4.17

V			VI			VII		
Temperature C°	Weight loss, %	Difference, %	Temperature C°	Weight loss, %	Difference, %	Temperature C°	Weight loss, %	Difference, %
670	0		680	0		80	0	
710	0.66	0.66	690	0.40	0.40	110	1.20	1.20
820	0.66	0.00	820	0.40	0.00	820	1.20	0.00
840	1.41	0.75	850	4.40	4.00	870	4.39	3.19
890	2.72	1.31	960	4.85	0.85	920	4.82	0.43
940	3.33	0.61						
970	3.59	0.26						

An X-ray study of powders has shown the similarity of all micas and the identity of their Debye powder patterns with the standard. For that reason, these data are omitted here.

ANALYSIS OF THE RESULTS

The results of chemical and x-ray analyses were almost identical for all samples; on the other hand, the dehydration curves did show some differences. Accordingly we shall discuss them in more detail.

As already pointed out, there are three types of dehydration curves for the Sayan muscovites (see Figure 1).

We assign samples I and II to the first type. They begin to get dehydrated at temperatures of 850 to 900° and they lose all of their water in the temperature range below 980°C. Some 80 to 90% (relative) of water is lost most rapidly, and almost isothermally; the remaining 10 to 20% is lost by muscovite at a slower rate.

These two samples represent a typical muscovite [3]. One of them (I) is from the quartz-muscovite fringe where it has been formed under high-temperature conditions; the other (II) comes from veinlets in microcline. These veinlets were formed probably in the crystallization process of microcline during the formation of the pegmatite body.

Sample III has an intermediate thermal characteristic, with the water loss beginning at 790°C (at a somewhat lower point) and proceeding along a steep curve. The dehydration is complete at 920°.

Three samples (IV, V, and VI) represent the second type of muscovite. They started to dehydrate at a temperate of 650 to 680°C, and lost 0. 38 to 0. 66% of their water on the way to 660-710°C. Samples from the quartz-microcline rock and from the replacing quartz-muscovite complex with only the remnants of microcline belong in this group. In both zones, muscovite was formed at the expense of microcline, with the formation conditions probably different in different parts of these zones;

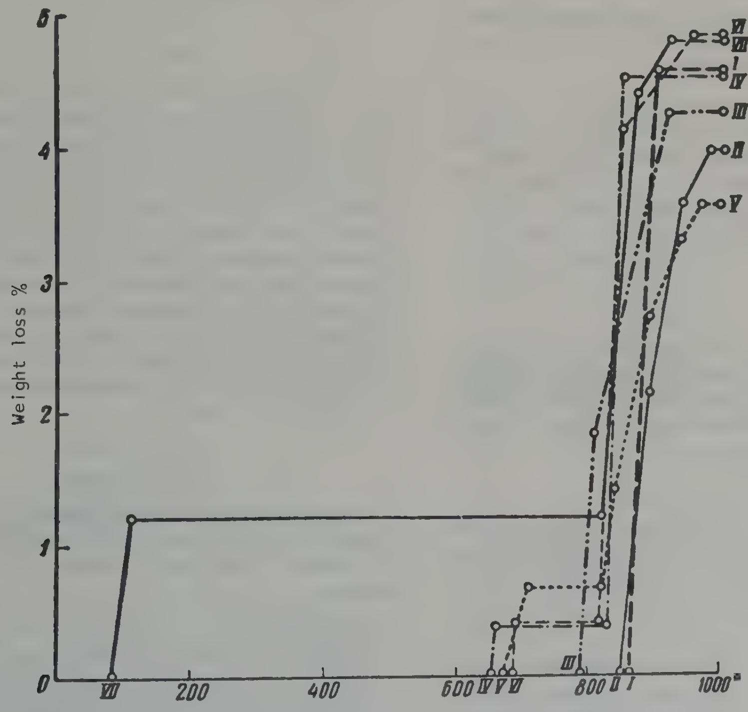

FIGURE 1. Dehydration curves for muscovite samples from different zones of a pegmatite vein.

I - sample 22 from the quartz-muscovite fringe; II - sample 44, veinlets in microcline; III - sample 257, from quartz-microcline rock; IV - sample 44-a, pockets in microcline; V - sample 3, quartz microcline rock; VI - sample 38, replacing quartz-muscovite complex; VII - sample 56, from albite zone intergrown with albite.

because of that, the newly-formed mica has a somewhat different thermal characteristic.

The third type of muscovite is represented by a single sample (VII) greatly differing from the others. It lost approximately a third of its water at a temperature of about 110°C. After a long temperature interval of equilibrium, the remaining water began to be liberated at 820°C. The terminal segment of this dehydration curve does not differ in any way from the other two. Sample VII comes from the massive microcline zone, at the intergrowth with albite replacing microcline. This is a newly-formed muscovite, originating in the albitization process which appears to have been the result of a hydrothermal action of alkali solutions of the pegmatite-zone minerals.

A thermal study of the Sayan muscovites by the dehydration-curve method demonstrates the difference in the thermal behavior of muscovites of different origins. This is quite important, because up to now there was no objective method for determining the origin of minerals, specifically muscovite.

Muscovite is a very common mineral; an objective determination of its origin may lead to solving the problem of the origin of minerals of the same paragenesis.

The structure of muscovite was first determined by W. Jackson and J. West [4], in 1930. It consists of layers of silicon-oxygen tetrahedrons and of aluminum ions surrounded by four oxygen and two hydroxyl groups (siffold coordination). Potassium ions are located between the bases of the silicon-oxygen tetrahedrons.

This structure of muscovite has been fully corroborated in the analysis of most samples. In standard micas, the hydroxyl group appears to have a thoroughly uniform position: it surrounds the aluminum ions.

By "standard" micas we mean those formed in high-temperature processes. In such micas, the determination of dehydration by physiochemical methods, such as by means of dehydration curves, at temperatures above 800°C, is done under almost isothermal conditions.

In processing the Sayan muscovite samples which carry a normal amount of water, we came across other dehydration temperatures where the water is lost in two installments and approximately one-third of it is lost at a comparatively low temperature, while most of it is lost at a temperature normal for muscovite.

In analyzing the structure of muscovites we find no explanation for that phenomenon. At the same time, it is unquestionable that there must be a connection. The distribution of hydroxyl groups is the most vulnerable structural point. These groups are not reflected in a X-ray picture and their distribution within the structure is hypothetical. We believe that the thermal behavior of a mineral provides a clue to the true arrangement of hydroxyl groups.

Our muscovite samples probably demonstrate two structural types: a full and a partial organization of structure.

Under the full organization, the arrangement of hydroxyl groups is probably well reflected in the structure, while an incomplete organization is not determined by the arrangement of hydroxyl groups. An incomplete organization may originate in the deficiency of silicon as well as in the large number of entries of the quadruple-coordination aluminum into silicon-oxygen tetrahedrons. In that and other anomalous examples the hydroxyl groups do not find their equivalent combinations and some of them end up with weakened bonds; such are the secondary micas originating in a superposition of the albitization processes on pegmatites, during a hydrothermal phase, as demonstrated in the mica example (sample VII).

The thermal behavior of muscovite, as noted in our samples, has a practical value. Up to now, we have used the morphologic method in recognizing different generations of minerals, by the nature of their intergrowth with other minerals, by their different crystal forms, and their color nuances. It appears that now it becomes possible to solve the problem of the formation temperature for some mineral groups (micas) from their thermal behavior, the degree of organization of their structure, and the relationship between the nature of the bonds within this structure and physiochemical conditions of formation of minerals.

CONCLUSIONS

The hitherto prevailing opinion on the perfect similarity in the thermal behavior of muscovite was based on the study of material of the same origin.

As a result of our study, we have determined the relationship between the thermal characteristics and the temperature of formation for muscovite, to wit: a high-temperature crystallization process produces a normal type muscovite; the replacement processes at the close of the pneumatolytic and during the hydrothermal phase apparently affects the organization of the structure, and the muscovite originating as a result of these processes has different thermal characteristics. In that event, some of the mica water is lost at a temperature considerably below the normal.

Our observations afford a means of distinguishing between muscovites of different origins by their thermal behavior. At the same time genetic characteristics can be determined for minerals, from the observed paragenetic relationships. The study of thermal behavior of muscovite should be extended to samples from other areas in order to obtain more comprehensive experimental material.

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Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Academy of Sciences, U. S. S. R.
Moscow

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THE TECTONICS OF SPITSBERGEN[1]

by

K. A. Klitin

Tectonically, Spitsbergen is an important place in the Polar Basin; it clarifies some structural features of the west Arctic. Despite the fact that part of the archipelago is buried under eternal ice, its general structural features are well known, thanks to the efforts of Norwegian, English, and Danish geologists. The study of this archipelago is facilitated by excellent outcrops along its coast with its picturesque, deeply incised fjords.

The earliest works in the beginning of this century have established that Spitsbergen is located in a zone of typical caledonids. This view has found its reflection in tectonic maps of foreign and Soviet geologists, who assign all folding of Spitsbergen to the Caledonian orogeny. However, K. Sandford [19, 20, 21], on the basis of his own observations, recognizes the presence of an ancient Precambrian massif in the eastern part of the archipelago.

His works led A. D. Arkhangel'skiy [1], A. Orvin [18], and H. Frebold [10] to the belief that a stable segment of crust lies under the Barents Sea. These views are best reflected by A. D. Arkhangel'skiy who shows the north terminal of the Russian platform in the Barents Sea area, on the tectonic map of the U. S. S. R.; he includes the eastern part of Spitsbergen in the platform, with the western part assigned to the Caledonian folding.

In recent years, new data have been obtained by English and Norwegian geologists (C. Wilson, [13]; J. McWhae, [16]; K. Sandford, [20, 2']; A. Hallam, [11]; W. Harland, [12, 13, etc.], allowing a better insight into the tectonics of these islands. The works of those investigators are the basis of this paper.

A study of the Spitsbergen structure is best started in the east where islands of the North East Land, Bol'shoy, Belyy, and some smaller islands carry out crops of metamorphic rocks represented by ortho- and paragneiss. These are quartz-feldspar, amphibole, hornblende, mica, garnet, and sillimanite gneisses with inclusions of marble. These gneisses form latitudinally to northeasterly trending folds, which are very gentle in some areas.

Resting directly on gneisses in the west of North East Land are non-metamorphosed rocks known as the Hecla Hoek "formation" in foreign literature. Its base is represented by dark slate and quartzite, 750 m thick; to the west, they are partially replaced by porphyrites and pyroclastics. Higher up, there are 3000 m of light-gray quartzite interbedded with dolomite and light-colored meta-shale which in turn change to units (150 m thick) of tillite-like conglomerate. The composite section culminates in dolomite and limestone 800 m thick carrying a Lower Cambrian fauna and known from both the east and west shore of the Hinlopen Strait. Inasmuch as the Lower Cambrian fauna is present only in the top of the composite section, most of the Hecla Hoek formation should be assigned to the Rhyphean and correlated with the Hyperborean of northern Norway and the Greenlandian of Greenland [15], with which it undoubtedly is similar, lithologically.

The Hecla Hoek rocks fill up a meridional trough about 100 km wide, where they form folds, often simple. The ancient gneiss basement is exposed in the cores of large anticlines. K. Sandford [21] and H. Frebold [10] note a gradual decrease in the intensity of dislocation, from west to east. Linear folds, overturned to the east, are developed only along the west margin of the trough. Intrusions of gray granite cut the gneiss but, according to W. Harland [12] nowhere penetrate the overlying rocks. The Hecla Hoek formation is cut only by minor bodies of pink granite and aplite.

The structure is substantially different in the western part of the archipelago (West Spitsbergen Island). The Hecla Hoek formation is present here, too; its complete section has been studied extensively by English geologists in the New Friesland Peninsula where it forms a large anticlinorium. The general constitution of the

[1]O tektonike Shpitsbergena.

section is somewhat similar to that of the neighboring North East Land. The difference lies in the considerable degree of metamorphism, decreasing upward; the greater thicknesses (up to 16,000 m); the appearance of thick volcanic sequences; and the absence of a clean-cut contact with underlying older rocks.

The base of the section is represented by gneiss of an undetermined stratigraphic position. It is believed that they may be Archean. They are followed by about 7000 m of unevenly metamorphosed carbonate and micaceous meta-shales and pink quartzites with relicts of cross-stratification. Fairly prominent is amphibolite whose origin is presumably related to metamorphism of basic extrusives and tuffs. Corresponding to the top of this interval in North East Land are lower intervals of the Hecla Hoek sequence of non-metamorphosed dark slates, quartzites, and volcanic rocks, 700 m thick (Figure 1).

Higher in the section, there are dark to light-colored quartzites (6000 m thick) changing to massive limestone (2000 m) with Collenia. They are followed by black to purple shale (700 m) with a horizon of tillite-like conglomerate (300 m) consisting of angular chunks and fragments of underlying limestone and dolomite and of assorted gneiss, quartzite, mica schist, jasperite, gray granite, and porphyrites. The section terminates with dolomite and dolomitic limestone (200 m) with Salterella rugosa, Obolus; and massive mottled limestone (600 m) with trilobites Hystricurus, Bolbocephalus, Batyurellus, brachiopods Archaerthis, and the gastropod Macluritella. Everywhere in Scotland and Greenland, Salterella characterizes the Lower Cambrian [11]. The faunal assemblage in this limestone points to its Lower Ordovician age. The Middle and Upper Cambrian probably are altogether missing, which is also typical of Greenland.

A complete Hecla Hoek section is not traceable in other areas of Spitsbergen, because of its complex tectonics. Present in the South Point area [17] are its upper intervals beginning with dolomite and oölitic limestone (400 m), changing upward to gray phyllite. This interval is presumably Precambrian. Higher up, there are limestone and shale with Lower Cambrian trilobites Olenellus and Serrodiscus, pteropods Hyolithellus, gastropods, and brachipods. Present in the overlying limestone and shale (1700 m) are typical representatives of the Lower Odovician North American fauna (brachipods, cephalopods, gastropods).

Thus, in the Hinlopen Strait area, there is a sharp increase in thickness (fourfold) from east to west, along with the appearance of older, metamorphosed rocks, all in a zone 15 to 20 km wide.

There are appreciable differences in the tectonics. In West Spitsbergen Island, the Hecla Hoek rocks form linear meridional folds, commonly overturned to the east. The folding is combined here with faulting, which results in a complex scaly structure of some areas.

Anticlines and synclines are identifiable within the folded zone. A large anticline, about 150 km long is present in the New Friesland area where the basal interval of the Hecla Hoek formation is exposed in its core. Associated with it in the Hinlopen Strait area to the east is a narrow syncline filled up with the above-mentioned Rhyphean and lower Paleozoic rocks, whose total thickness is as much as 16 km.

Another anticline is located in the Cross Fjord area, in the western part of Spitsbergen; its structure is practically unknown, as yet.

A trough in intensively disturbed Hecla Hoek rocks between the New Friesland and Cross Fjord anticlines is filled with thick (8000 m) Devonian lagunal-continental coarse-clastic red beds similar in origin and structure to the Old Red sandstone of Scotland and Norway.

Present at the base of the Devonian are coarse pebble to boulder conglomerates with pebbles from the underlying Hecla Hoek rocks. The conglomerate changes to coarse sandstone and gravel interbedded with shale and limestone. Very prominent in the upper and lower intervals are fine-grained sandstone and shale, red to gray and green.

Occurring throughout the section are well-preserved remains of Lower and Middle Devonian fishes similar to those of Scotland, also ostracods and plants.

The above-named trough has the trend of the basement structures. It is outlined on its flanks by long-active faults [16] along which its rocks are disturbed while remaining almost horizontal in its central part.

In the southern part of the archipelago, all those structures are buried under a platform mantle gently dipping southeast and formed mostly by marine carbonate deposits of Carboniferous, Permian, Triassic, Jurassic, and Cretaceous age.

The most complete section of the mantle has been observed on West Spitsbergen Island where the upper Paleozoic and Mesozoic form a large trough trending northwest - southeast.

The base of that section is made up of Lower Carboniferous sandstone, conglomerate, and shale with beds of coal and gypsum, all being very inconsistent in thickness and distribution. They are followed by Middle to Upper Carboniferous and Permian siliceous limestone with gypsum (600 to 700 m), resting unconformably

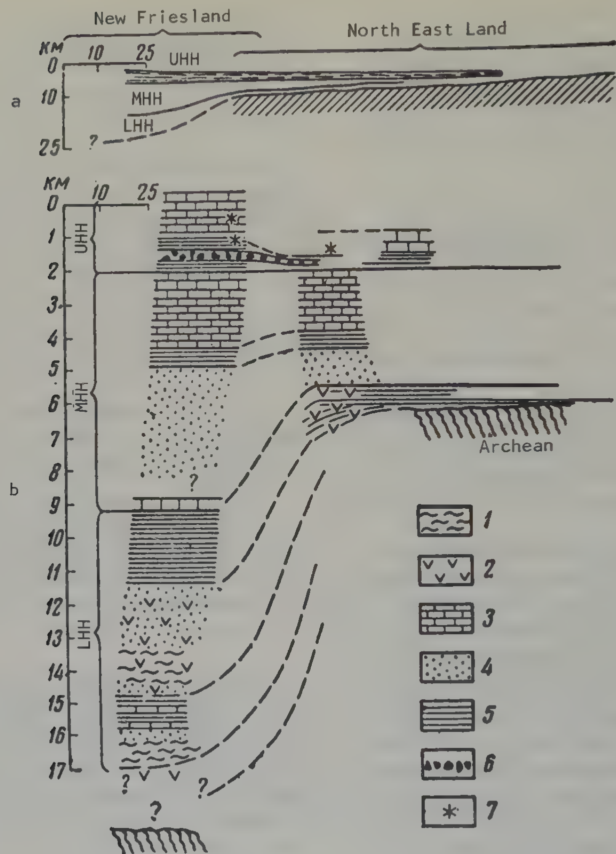

FIGURE 1. Diagrammatic stratigraphic section showing the relationship of Hecla Hoek rocks in New Friesland and North East Land (after W.V. Harland).

a - no scale exaggeration; b - vertical scale exaggerated 10 X; LHH - lower Hecla Hoek; MHH - Middle Hecla Hoek; UHH - upper Hecla Hoek; 1 - gneiss; 2 - volcanic rocks, partly altered (amphibolite); 3 - marble, limestone, dolomite; 4 - quartzite, sandstone, gravel; 5 - shale; 6 - tillite; 7 - fossiliferous beds.

either on the Lower Carboniferous or on the Hecla Hoek. The Mesozoic is made up mostly by areno-argillaceous rocks of Triassic, Jurassic, and Cretaceous age with ammonites and belemites. Its thickness locally exceeds 2000 m. Finally, there is a deep depression in the center of the trough, filled with conglomerate, sandstone, and shale (2000 m) of Tertiary age carrying considerable stores of high-grade coal [4, 5] toward the base. Even coarser clastic Tertiary rocks occur in a graben between the Prince Charles foreland and West Spitsbergen. Only the sides of the graben are visible, while its middle is submerged under the Foreland Sound.

The mantle structure is different in the east half of the archipelago. Here, the Lower Carboniferous is missing and the basement is overlain by flat Permo-Carboniferous limestone and Triassic shale. The Jurassic and Cretaceous beds are poorly developed. The mantle is not thicker than 1500 to 2000 m, while the Upper Paleozoic and Mesozoic and Cenozoic in the western part of Spitsbergen attain 4000 to 5000 m. Unlike West Spitsbergen, the eastern part of the archipelago is characterized by a wide development of Mesozoic traprock; as a result, the mantle is "stuffed up" with sill-like bodies of diabase, and basalt flows, very similar in composition to the traprock of the Siberian platform.

Thus, an analysis of new data on the stratigraphy and tectonics of Spitsbergen corroborates the earlier concept of a platform in the Barents

Sea area, or at least a large massif with a pre-Rhyphean folded basement.

This platform is directly observable only in the eastern part of the archipelago; however, there is indirect evidence of its present under the Barents Sea, as well. This is specifically indicated by the broad development of traprock volcanism on the Wiche Islands, Islands of Edge, Barents, and Franz Josef Land. Volcanism has not been observed in the Caledonian fold system, in the western part of the archipelago, where the platform mantle, too, has a different structure.

The caledonids proper are developed in West Spitsbergen Island. Here, the Hecla Hoek sequence, up to 16 km thick, is strongly plicated in linear folds. The terminal folding occurred in the Silurian, because gently folded Devonian redbeds rest unconformably on Cambro-Ordovician limestone.

In form and constitution, the Spitsbergen Devonian troughs are undoubtedly similar to Caledonian intermontane troughs in England, Norway, Kazakhstan, and the Altay-Sayan province, while differing from some of them in the near-absence of evidence of Devonian volcanism.

FIGURE 2. Tectonic map of Spitsbergen. Compiled by K.A. Klitin from data from A. Orvin, K. Sandford, W. Harland, O. Holtedahl, and others.

1 - outcrops of pre-Rhyphean folded basement rocks; 2 - Rhyphean trough at the edge of an ancient platform; 3 - Caledonian fold system; 4 - Caledonian granite; 5 - intermontane troughs in the Caledonian folded basement; 6 - mantle of the ancient platform; 7 - Caledonian platform mantle; 8 - traprock; 9 - Tertiary troughs and graben; 10 - Quaternary volcanoes; 11 - boundaries of structural stages; 12 - boundaries of the platform mantle; 13 - assumed structural lines; 14 - known long-active faults; 15 - other faults (serrated lines indicate dip of fault planes); 16 - strike of pre-Rhyphean basement rocks; 17 - elements of occurrence.

An important feature of the Spitsbergen caledonids as well as those of Norway and Greenland is that they all were most intensively downwarped in the Rhyphean, with the downwarping movement slackening in the Cambrian and Ordovician.

Of particular interest is the junction zone of the alleged Caledonian platform and Caledonian fold system. The transition to typical caledonids takes place in a zone not over 15 to 20 km wide, in the Hinlopen Strait area, where the Hecla Hoek section abruptly increases in thickness, by a factor of four, with the appearance of extrusives in its metamorphosed and linearly folded beds. Such radical changes in thickness suggest a fault junction between an ancient platform and the caledonids, which originate, according to N. S. Shatskiy [8], in connection with a high position of the folded basement of these platforms, i. e., near shields. It should be noted, however, that the platform edge in front of the caledonids was downwarped to form a trough, in the Rhyphean, probably at the same time the Rhyphean-Caledonian geosyncline was formed and developed.

Similar downwarps in front of the caledonids have been observed in regions of classic fault structures. For example, the southeastern part of the Erin platform of Scotland is countersunk and overlain by non-metamorphic Torridonian, Cambrian, and Ordovician sediments [6]. Here also may belong the zones of unmetamorphosed sparagmite sequences of south Norway and Sweden as well as the Hyperborean formations of Finnmark with the Norwegian caledonids thrust over them. Present in Greenland [9], along the eastern margin of the ancient shield, is a trough filled with non-metamorphic Late Precambrian (Greenlandian), Cambrian, and Silurian rocks, whose structure is very similar to the non-metamorphic Hecla Hoek of North East Land.

Such troughs are best assigned to a group of structures designated by Ye. V. Pavlovskiy [7] as pericratonic subsidences, although their magnitude is incomparably smaller than that of the Angara-Lena trough described by Ye. V. Pavlovskiy for the southeast margin of the Siberian platform.

We believe that the fault junction between the Caledonian zone and its platform in the Spitsbergen area is also indicated by the tillite-like conglomerates similar to those present in the top of the Precambrian of Greenland, Scotland, and Scandinavia. They are developed usually along the junction zones of shields with Caledonian fold systems and are not traceable laterally over long distances. Most of these "tillites" consist of chunks and pebbles of the underlying rocks, with pebbles of an unknown origin missing or nearly so. The origin of these "tillites" is probably connected with a definite stage in the development of faults bordering the ancient platforms, with a simultaneous and sharp relative uplift of the shield edges in tectonic shelves with conglomerates formed at their foot. In other words, their origin is that established by V. N. Grigor'yev and M. A. Semikhatov [2] for "tillites" in the northern part of the Yenisey Range.

It is to be noted that this view of the Spitsbergen structure is not shared by all geologists. Some investigators believe that, instead of an edge of the Russian platform, the North East Land area presents a large anticline toward which occur the changes in thickness, facies, and metamorphism of the Hecla Hoek series mentioned above. Those authors cite the considerably disturbed nature of these rocks in some areas of North East Land, along with the presence of small intrusions of Caledonian granite, as arguments in favor of a geosynclinal development of this region, in the Rhyphean and early Paleozoic.

We find it difficult to conceive of an anticline with a core of highly metamorphosed pre-Rhyphean rocks, over 200 km wide. The marginal segments of ancient platforms usually are folded to some extent, and cut by intrusions, as an effect of orogenic movements taking place in the neighboring geosynclines. Such phenomena have been observed along the south margin of the Siberian platform, and along the Erin platform and the Greenland shield.

The presence of a Rhyphean trough, superimposed on the ancient gneiss complex of North East Land, as well as the structure of the junction zone with Caledonian folding in the Hinlopen Strait area, suggests the presence of a true platform edge in the eastern part of Spitsbergen, rather than a small median massif or an anticline.

The platform which appears to occupy most of the Barents Sea is separated from the Russian platform by a deep Rhyphean trough in the area of Timan and the Kanin and Rybachiy peninsulas. It differs from the Russian platform in the history of its development, as witness the Mesozoic volcanism typical of the ancient Greenland shield and the Erin platform.

The Spitsbergen caledonids are a direct continuation of those of Norway, which veer north in the Tromso area and extend to Spitsbergen by way of Bear Island. Undoubtedly, they were connected with Greenland, as well, as witness their spatial position and the startling similarity between the Greenland and Hecla Hoek section, as well as their Cambrian and Ordovician faunas.

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Geological Institute
Academy of Sciences, U. S. S. R.,
Moscow

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FOSSIL FAUNA AND STRATIGRAPHY OF THE COAL MEASURES IN THE NORTH SOS'VA BASIN[1]

by

R. Z. Genkina

As commissioned by the Section of the Geology of Coal at the former All-Union Scientific Research Institute of Coal (VUGI), the author studied a number of brown-coal deposits on the east slope of the north and subpolar Urals in the summer of 1957. Forty samples with plant imprints were collected from the Tol'insk and Otor'insk deposits, and the north Sos'va brown coal basin. Their identification, along with field data and published material, is the subject matter of this paper.

The processing of even such a small paleobotanical collection is not without interest, in two respects: first as a contribution to the knowledge of the Mesozoic fauna from the north Sos'va basin, inasmuch as there have been no findings of identifiable plant remains on the east slope of the north Urals, above 60°N latitude, and ours are the first such finding; secondly, data obtained from this fossil flora are helpful in making a more precise age determination for the north Sos'va coal measures.

The north Sos'va brown-coal basin extends in a narrow band along the east slope of the Uralian Range, within the Tyumen' and the north of Sverdlovsk Oblast. It is thought that this basin extends north, as far as Salekhard.

Four brown-coal deposits have been discovered in the basin. From south to north, they are Ust'-Man'insk, Lopsinsk, Tol'insk, and Otor'insk; a number of prospective areas and districts are suggested in the Mesozoic-Paleozoic contact zone (see map).

The largest is the Otor'insk deposit in the Otor'ya valley, the right tributary of the Tol'ya. The Tol'insk deposit is located 5 km west of there, on the right bank of the Tol'ya. Both deposits fall within the Berezovsk district, the Khanta-Mansiysk National Circuit, the Tyumen' Oblast, about 300 km north of the nearest railroad station, Polunochnoye.

The geologic structure of the Otor'insk and Tol'insk deposits is, briefly, as follows: they both are associated with a meridional belt of Mesozoic and Cenozoic outcrops extending over 500 km along the eastern shelf of the Uralian Paleozoics, from Ust'-Man'ya settlement north to Salekhard.

In connection with the general easterly plunge of the Paleozoic basement, Mesozoic and Cenozoic deposits thicken rapidly in that direction. Mesozoic deposits are generally gently dipping monoclinally to the east (1-2 to 4-6°) and are complicated by secondary folding.

The Tol'insk and Otor'insk deposits are associated with a horst of the so-called "Mansiysk uplift" in the Paleozoic basement, 25 km east of Paleozoic outcrops in the hill zone of the north Urals hill belt. This uplift brings to the surface lower units of the Mesozoic section, made up of coal-bearing deposits. Its position as a buried swell extended north-northeast, has determined the occurrence of its sedimentary mantle: a large anticlinal structure with the Tol'insk deposit on its west limb and the Otor'insk deposit in its core and east limb.

According to V. A. Lider [4], the base of the Mesozoic section in the north Sos'va basin is represented by a motley formation of an ancient weathered zone consisting of multicolored montmorillonitic and kaolinitic clays. They rest on Upper Tournaisian rocks and are overlain by coal measures, presumably of the Upper Jurassic. This formation is up to 20 m thick.

Higher up, there are coal-bearing deposits which this author subdivides into three formations; reading upward, they are the Yany-Man'insk, Tol'insk, and Otor'insk. The Yany-Man'insk formation is represented by alternating polymictic conglomerate, calcareous sandstone, carbonaceous shale, and thin coal beds, with the conglomerate and sandstone predominating. This formation is 40 to 50 m thick. Its deposits are not developed everywhere, being partly eroded in the western marginal part of the basin.

The Tol'insk (sand-gravel) formation rests erosionally on the underlying formation and is

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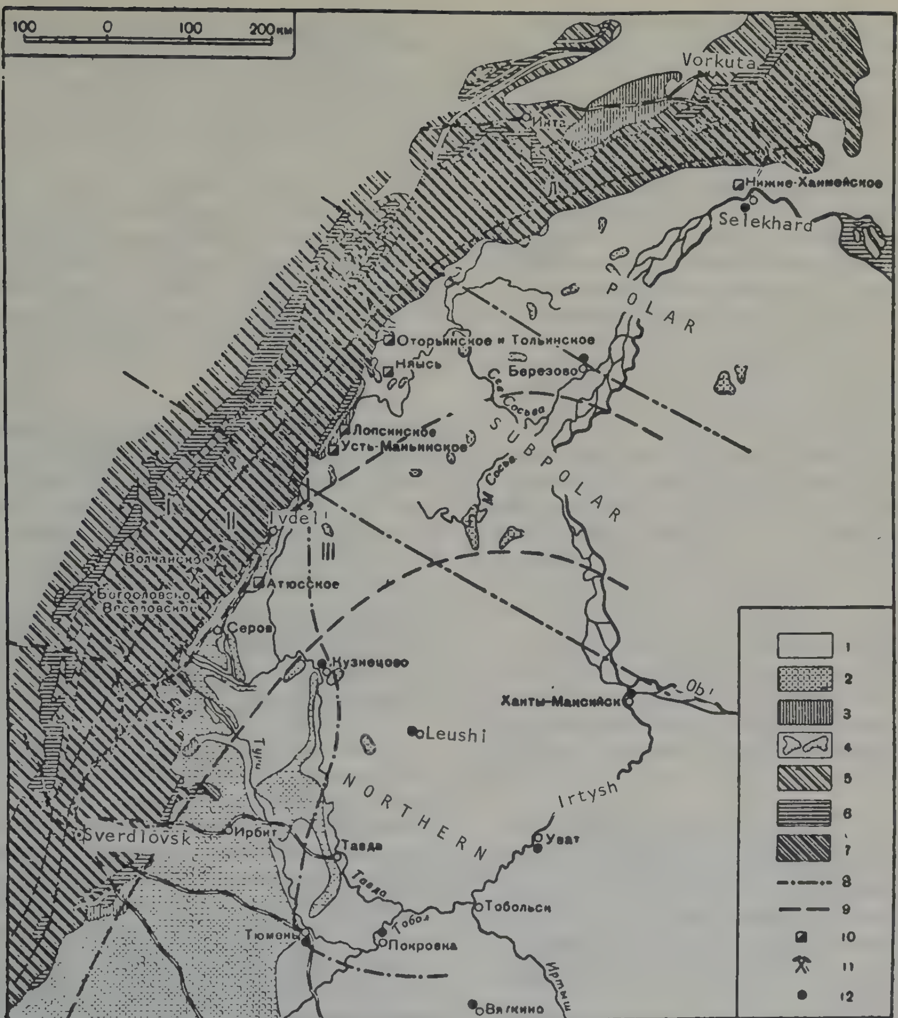
[1]Iskopayemaya flora i stratigrafiya uglenosnykh otlozheniy Severo-Sos'vinskogo basseyna.



Generalized index map of the east slope of the north and subpolar Urals.

1 - Quaternary deposits; 2 - Tertiary deposits; 3 - Cretaceous; 4 - Jurassic; 5 - Permian; 6 - Carboniferous; 7 - undifferentiated Paleozoic deposits; 8 - west boundary of Middle and Upper Jurassic coal measures; 9 - structures: I - Central Uralian anticlinorium; II - Greenstone synclinorium; III - East Uralian anticlinorium; 10 - brown coal deposits; 11 - coal mines; 12 - stratigraphic tests.

developed in the Tol'insk deposit proper as well as within the frontal depression; it is missing from the section in the Otor'insk deposit. This formation is represented by gravel and sand of a quartz, quartz-feldspar to arkosic composition. It carries subordinate glauconite-quartz sand, silt, and thin beds of brown coal, with the sand predominating; thickness, 80 m.

The third formation, the productive Otor'insk, is developed throughout the north Sos'va basin, except for the horst uplifts in the Paleozoic basement and those areas where they have been obliterated by glaciation. It is represented by alternating kaolinitic hydromicaceous shale, polymictic sandstone and pelites, and brown coals. The coal beds, particularly the upper one, are consistent in thickness. The shales are light-gray to gray and "chocolate", greasy to the touch, with a characteristic streamlined break. The "chocolate" shales carry a considerable amount of plant remains.

The Otor'insk formation contains up to seven coal beds, the uppermost of which, the so-called "Main" bed, stands out in thickness (up to 10.75 m) and consistency throughout the mines. The other beds are less consistent,

their thickness not exceeding 1.5 or 2.3 m. This formation is 40 m thick.

All these deposits are continental, were formed in lakes and flooded peat bogs near a seashore and at times invaded by the sea. Such short-lived marine transgressions are fairly commonly represented in the Tol'insk and Otor'insk deposits, where marine beds occur among the continental. Thus all three formations include silts and glauconite-quartz sands with authigenic glauconite, sponge spicules, broken pelecypod shells, and foraminifera.

Also probably marine are the beidellite shales occasionally penetrated by some boreholes in the Otor'insk deposit.

In all its sections, this coal-bearing sequence is overlain by fossiliferous Upper Oxfordian deposits represented by kaolinitic hydromacaceous shales, carbonaceous at the base and carrying marine fossils in the top. These shales also include lentils and consistent horizons of siderite concretions. Occasionally present at the lower contact of shale and the coal measures are small additions of sand and gravel. A thin layer (0.05 to 0.1 m) of ferruginous conglomerate of well-rounded small quartz pebbles is locally present at the base of the shale; in places, it changes to quartz sandstone up to 2 m thick.

North of the Tol'insk and Otor'insk deposits, along the Yany-Man'ya River, the coal measures are capped by gray shale with concretions and intercalations of ferruginous limestone. N. P. Mikhaylov [5] identified here an Upper Oxfordian fauna of Ringsteadia cf. marstonensis Salfeld; R. aff. evoluta Salf.; and Cardioceras alternans (Buch).

The thickness of Upper Oxfordian deposits ranges from 2-4 m in the marginal zone of the north Sos'va basin (Ust'-Man'ya) to 40-45 m in the Otor'insk and Tol'insk deposits.

The coal measures themselves are extremely poor in organic remains. V. A. Lider [4] mentions rare pelecypod molds, sand with broken up shells, rare leaf impressions, mat-like horsetail accumulations, and poor assemblages of spores and pollen.

The author has observed cores from 22 boreholes, with a total thickness over 2000 m, throughout the Tol'insk and Otor'insk deposits. Detrital plant remains occur throughout the entire coal-measure section, being most abundant in the vicinity of the coal beds. Present along with detritus are coarser plant remains represented by leaf imprints, often quite well preserved.

Plant remains are most common in the "chocolate" shale; they are represented chiefly by extremely fine imprints, in places with a small amount of coal dust. In some instances (e.g., ginkgoes), the plant substance has been preserved as a fine carbonaceous film. We have succeeded in collecting a total of over 40 specimens with plant imprints, in cores from 12 boreholes.

All plant remains present in this collection were taken into consideration during the processing of material; they were compared with those previously described in paleophytologic works. However, because of the fragmentary state of many of them, a complete identification was not possible.

The following fossil plant species have been identified: Coniopteris hymenophylloides (Brongn.) Seward, Cladophlebis sp. cf. whitbiensis Brongn., Cl. sp. cf. denticulata (Brongn.) Fontaine, Cl. sp., Equisetites sp., Taeniopteris vittata Brongn., Nilssonia vittaeformis Pryn., N. sp. ex gr. orientalis Heer, N. sp. cf. polymorpha Schenk., N. sp. ex gr. denticulata Thomas, Ginkgo sp., Sphenobaiera longifolia (Pom.) cf. Florin, Phoenicopsis angustifolia Heer, Czekanowskia rigida Heer, Pityophyllum Nordenskioldii (Heer) Nathorst., Podozamites angustifolius Eichw.

These 16 species, identified in the Otor'insk coal measures of the Tol'insk and Otor'insk deposits, represent the first specific assemblage of Mesozoic flora determined in the north Sos'va basin and the east slope of the north Urals in general; it appears to be far from complete for the Mesozoic flora of that region. A more comprehensive paleobotanical description may be written in the future, through special efforts of collecting paleobotanical material, possibly in connection with the exploration work widely developed here in recent years and with a further accumulation of cores from coal-bearing deposits. A careful bed-by-bed collecting of plant remains from the entire section is necessary in determining the over-all composition of the flora and the change in its elements, in time.

Before going into the problem of the age and geographic distribution of the species named above, we shall describe briefly the over-all composition of the north Sos'va flora. The principal plant forms are as follows: ferns, 5; horsetails, 1; cycadophytae, 5; ginkgoes, 4; conifers, 2.

The most prominent in numbers and variety are cicadophytae represented by two genera: Taenipteris and Nilssonia. The Cladophlebis ferns are less prominent, being represented by small-leaf forms of type Cladophlebis whitbiensis and C. denticulata. The single imprint of Coniopteris hymenophylloides is a rarity in this collection; this may be due to the poverty of the collection as well as to the fact that this fern was inconspicuous in that flora.

The narrow Czekanowskia leaves as well as the isolated broader linear leaves of Phoenicopsis are fairly common, locally forming matted accumulations; the true ginkgo leaves (Ginkgo and Baiera) are considerably less common.

Common among the conifers are Pityophyllum nordenskioldii, while representatives of genus Podozamites are extremely rare.

A typical feature of this flora is its comparatively large cycad content (over 31%), which constitutes the bulk of it; also the presence, be it only in a single specimen, of the Coniopteris hymenophylloides fern.

Neither cycadophytae nor any representatives of genus Coniopteris have been identified from the familiar and geographically close Rhaetic to Lower Liassic fauna in coal measures of the Volchansk, Bogoslovsk, and Veselovsk brown-coal deposits on the east slope of the north Urals. Present in the plant assemblage from coal formation C of those deposits also are a number of Cordaites-like plants (Uralophyllum), the relicts of older floras. These relict plants are missing in upper intervals of the coal measures, which suggests [2] partial rejuvenation of the plant assemblage during the interval of deposition from the two upper coal formations A and B and to the Lower Liassic.

The flora of the productive Otor'insk formation in the Tol'insk and Otor'insk deposits is quite different from the Volchansk-Bogoslovsk-Veselovsk flora of the north Uralian east slope in its younger aspect. The only species common to these floras are Cladophlebis denticulata, Phoenicopsis angustifolia, Czekanowskia rigida, and Pityophyllum nordenskioldii, all typical elements of the Siberian floral province. In conjunction with the true gingkoes, these species constitute a younger nucleus of the Volchansk-Bogoslovsk flora and are concentrated now in and near the upper coal-bearing formations A and B, in those coal deposits.

The fauna of the Otor'insk (productive) formation in the Tol'insk and Otor'insk brown-coal deposits of the north Sos'va basin shows a great similarity to Middle Jurassic floras from the Orenburg-Orsk region coal measures (the east Ural brown-coal deposit); the Dzhenishke formation of the Ilek basin, west Kazakhstan; and the Dossor formation, the Emba region; as well as to the Middle Jurassic Kamenka flora in the Izyum area along the Don, in the Ukraine; and the oölitic Yorkshire flora of England.

In addition, a cognate plant assemblage (Coniopteris maakiana, Cladophlebis denticulata, and Pityophyllum nordenskioldii) has been observed in Upper Jurassic continental coal-bearing deposits penetrated by a deep borehole in the Tyumen area.

Although the unquestionable presence of individual forms of these faunas has been established for single deposits only, there are index forms common to all of these deposits. They include cycadophytae, represented in all floras by several genera; the Coniopteris ferns with their diversified species and Cladophlebis with its usually widely distributed species of Cladophlebis whitbiensis, C. denticulata, C. hairburnensis, etc., all widely distributed in some deposits (east Uralian brown-coal deposit); and true ginkgoes with numerous species and plants similar to them (Phoenicopsis, Czekanowskia), in the others (Dzhenishke, Dossor, and Otor'insk formations; see Table).

Thus the analysis of the systematic composition of the flora for the Otor'insk (productive) formation from the Tol'yan and Otor'yan brown-coal deposits, the north Sos'va basin, and its comparison with similar floras from other regions, suggest that it is generally characteristic of the Middle Jurassic.

Inasmuch as the Otor'insk (productive) formation, which carries this plant assemblage, is overlain by a shale member, 40 m thick and tentatively assigned to the Oxfordian, and this latter is overlain, in turn, by marine deposits with a known Upper Oxfordian fauna, the upper age limit of the plant-bearing formation may be assumed as Callovian, i. e., Lower Oxfordian.

Accordingly, the deposition of the entire north Sos'va basin coal-bearing section including the Yany-Man'insk. Tol'insk, and Otor'insk formations, started presumably at the close of the Middle Jurassic and continued in the Callovian, possibly including some of the Lower Oxfordian.

Supporting evidence for a Middle to Upper Jurassic age of the north Sos'va basin coal measures is presented by its spore-pollen assemblage. According to V. V. Zauer, it is characterized by a predominance of the Leiotriletes group spores (maximum, 40. 8%), with a maximum of 35% of Lycopodium genus spores, family Osmundacea. Comparatively abundant among the gymnosperms if the pollen of genus Picea (maximum, 18%) and genus Ginkgo (maximum, 13. 6%).

Only a Rhaetic - Lower Liassic flora has been known up to now from the east slope of the north and middle Urals; it comes from coal-bearing deposits extending from Yemanzhelinka in the south to Volchanka in the north.

The Otor'insk (productive) formation fauna is younger Middle Jurassic and appears to represent a subsequent stage in the development of a Jurassic fauna on the east Uralian slope. For the time being, it is the only known flora from Middle to Upper Jurassic coal-bearing deposits developed on the east slope of the north and subpolar Urals.

Correlation of the flora from the Otor'insk (productive) formation of the Tol'insk and Otor'insk brown-coal deposits, the north Sos'va basin, with similar floras from other deposits

Nos.	Plant forms	Regions								
		Yorkshire oölitic (England)	Kamenka River, Izyum area (Donbas)	East Uralian brown coal deposits (west Kazakhstan)	Dzhenishke formation, Ilek River (west Kazakhstan)	Dossor formation Emba region	Middle Jurassic coal measures, near Tyumen'	Volchansk brown-coal deposit	Bogoslovsk brown-coal deposit	Veselovsk brown-coal deposit
1	Coniopteris hymenophylloides (Brongn.) Seward	+	+	+	+	+	0	—	—	—
2	Cladophlebis sp. cf. whitbiensis Brongrn.	+	—	+	+	+	—	—	—	—
3	Cl. sp. cf. denticulata (Brongn.) Fontaine	+	0	+	+	—	+	+	+	+
4	Equisetites sp.	0	0	0	0	0	—	—	—	—
5	Taeniopteris vittata Brongn.	+	+	+	—	0	—	—	—	—
6	Nilssonia vittaeformis Pryn.	—	0	+	+	+	—	—	—	—
7	N. sp. ex gr. orientalis Heer	—	+	+	—	—	—	—	—	—
8	N. sp. cf. polymorpha Schenk.	—	+	0	—	—	—	—	—	—
9	N. sp. ex gr. denticulata Thomas	—	+	+	—	—	—	—	—	—
10	Ginkgo sp.	0	0	0	—	—	—	—	—	—
11	Sphenobaiera cf. longifolia (Pom.) Florin	—	—	0	—	0	—	—	—	—
12	Phoenicopsis angustifolia Heer	—	—	+	0	0	—	+	+	—
13	Czekanowskia rigida Heer	+	+	+	—	+	—	+	+	+
14	Pityophyllum Nordenskioldii (Heer) Nathorst.	—	+	+	0	—	+	—	+	—
15	Podozamites angustifolius Eichw.	+	+	+	0	0	—	+	+	—

Note: + - similar forms; O - cognate forms; — - not observed.

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Institute of Geology and Exploitation of Mineral Fuels, Academy of Sciences, U. S. S. R., Moscow

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BRIEF COMMUNICATIONS

WORKS IN MARINE GEOLOGY IN THE ATLANTIC[1,2]

by

M. V. Klenova

The work on marine geology in the Atlantic was carried on in accordance with the schedule of the International Geophysical Year, for the project, "The Structure of the Oceanic Bottom" proposed by the U. S. S. R. The 1957-1958 voyages of the oceanographic ships "M. Lomonosov", "Equator", and "Sedov", carried out the sounding of the bottom, sampling with core barrels and dredges, and a study of material in suspension by the microscopic and weight method. All material is now being processed. The exploration work is still in progress.

By August, 1959, 169 bottom cores were collected; they were 6 to 574 cm long. In addition, about 150 bottom dredge samples, including those from depths over 5000 m were taken during the fifth voyage of the SS M. Lomonosov (April-June, 1959). Material in suspension was collected from 1500 suspension filters, and microscopic study of material in suspension was done for 525 water samples.

A microscopic study of the composition for the silty fraction of sediments in order to evaluate the relative content of mineral and biogenic components was performed on the SS M. Lomonosov during the voyages. Carried out during the 1959 M. Lomonosov voyage was a mechanical analysis of the sediment's surface layer by means of a reticulate eyepiece which makes it possible to arrive at the weight percent after counting grains of certain sizes (the I. K. Avilov method). During the same voyage, the Oceanology Institute Akad. Nauk U. S. S. R. submarine photocamera, developed by N. L. Zenkevich, was used for the first time.

The SS M. Lomonosov carried out bottom-sounding along her entire course. The area most studied during the IGY was the northeast Atlantic, from Iceland to the latitude of Gibraltar and from the British Isles and the Iberian Peninsula to Newfoundland (Figure 1). The fifth voyage of the SS M. Lomonsov, in 1959, was mostly along the 30° meridian, west longitude, from Greenland to the latitude of Rio de Janeiro (Figures 1 and 2).

The bottom sounding brought out the essential features of bottom relief in the northeast Atlantic, where it is related to geologic structures trending northeast to meridionally. As in other basins (the Barents and the Caspian seas, [1]), they are crossed by sublatitudinal elements, trending chiefly northwest. This results in S-shaped bends in the submeridional structures. Distinctive in shape in the North Atlantic, are the more ancient relief elements related to Caledonian folding in Europe, as are also the younger forms, including the volcanoes.

During the SS M. Lomonosov expedition sponsored by the Marine Hydrophysical Institute, Academy of Sciences, U. S. S. R., its Mensuration Laboratory (A. P. Metal'nikov, Director) discovered several new submarine volcanoes standing 1 to 2 km above bottom. Such are the submarine mountains near 30° west longitude, south of the Azores, at 38°58' and 33°30' north latitude; also north of the Brazilian trough, and north of the Romanche trough. These newly discovered submarine mountains have been named "Mikhail Lomonosov", "Academician Krylov", "Professor Berezkin", and "Professor Mesyatsev". The "M. Lomonosov" bank was discovered during the 1958 soundings and studied in more detail in 1959. The bottom dredge picked up a basalt chunk here; a piece of lava outcrop was chipped off, 1.5 mile to the north. On the "Academician Krylov" submarine mountain, the bottom dredge brought up fragments of volcanic tuff and lava, as well as volcanic bombs. A submarine photograph revealed a lava flow only slightly covered locally by foraminiferal sand.

The analysis of composition of the silt fraction allows a differentiation of clastic,

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[1]Raboty po geologii norya v atlanticheskom okeane.
[2]Read before the International Oceanographic Congress, New York, September 8, 1959.

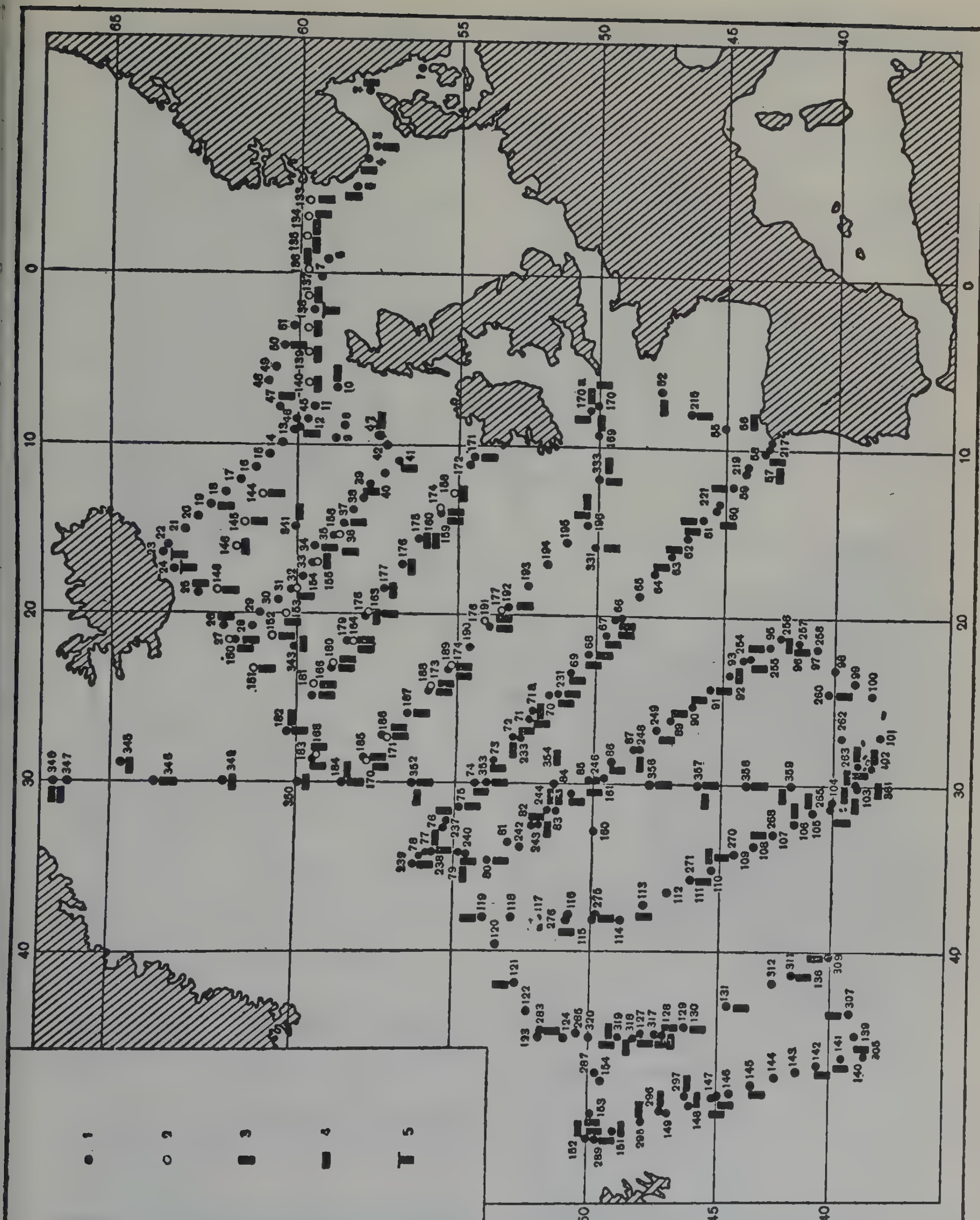

FIGURE 1. Stations of the exploration ship M. Lomonosov in the study of submarine geology of the northeast Atlantic.

For symbols see Figure 2.

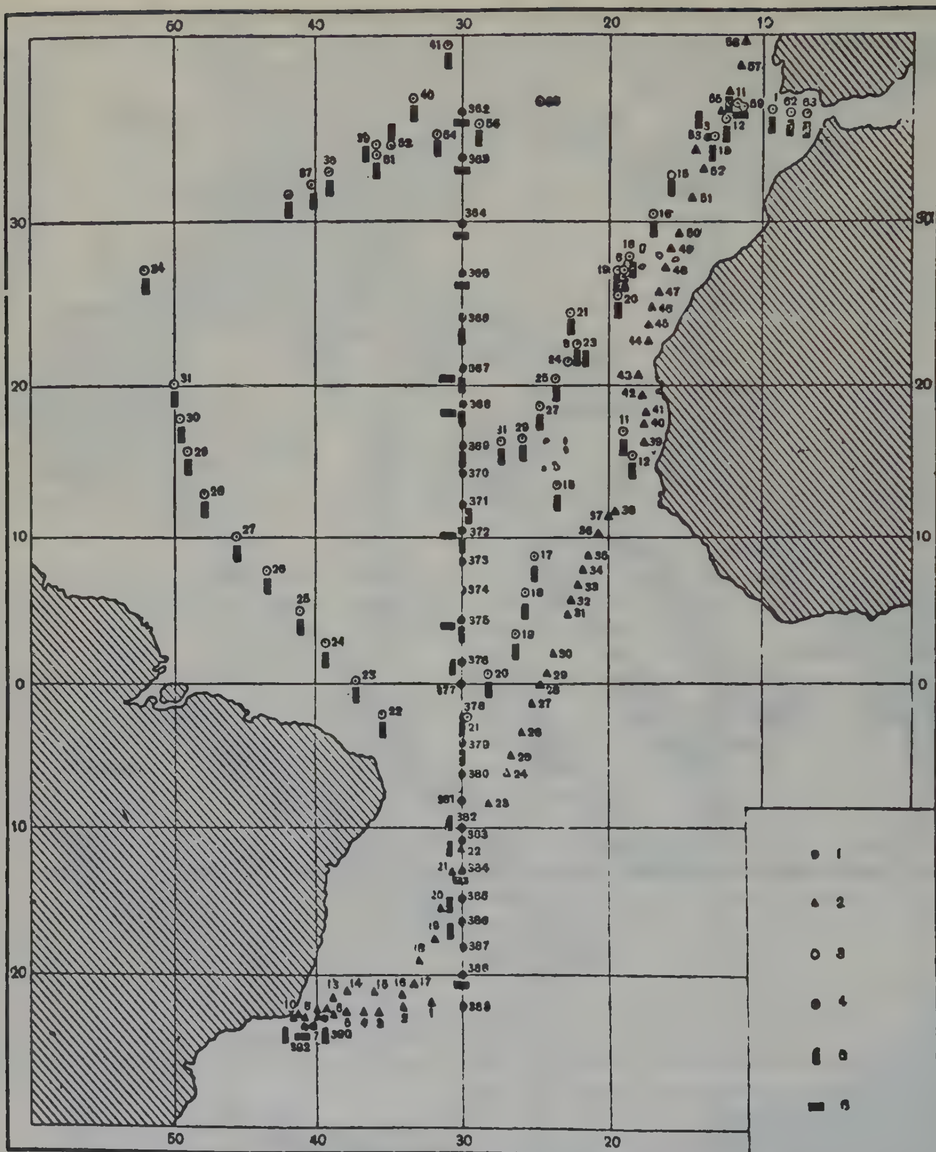

FIGURE 2. Stations of geologic work in the central Atlantic.

1 - stations of SS M. Lomonosov; 2 - suspension sampling by SS M. Lomonosov; 3 - bottom sampling stations of SS Sedov; 4 - cores; 5 - bottom dredging.

clastic-carbonate, and carbonate facies. Prominent among the latter are coccolithophoric sediments with coccoliths making up to 90% of the silt fraction (in the number of grains). A close relationship has been established between the composition of that fraction (0.1 to 0.01 mm) and the bottom relief and water body.

In the northern part of the ocean, the number of mineral grains decreases away from shores and from submarine mountains, with a parallel increase in the biogenic components, especially calcareous algae — Coccolithophoracae and to some extent foraminifera and sponge spicules. Present in the African trough, with Atlantic and Antarctic waters commingling at its bottom, are coccoliths along with a considerable amount of mineral grains. On the other hand, coccoliths are absent at the same depths in the Brazilian trough occupied by the Antarctic waters alone. The silt fraction from the Brazilian trough clay ooze contains only the mineral grains.

In compiling the bottom section of the Marine Atlas of the U. S. S. R. (Vol. II, Map 13, 1953; also "Great Soviet Encyclopedia", Vol. 13, "Bottom Maps", 1952), advantage was taken of data of the numerous expeditions into the Atlantic [1, 2]. After their interpretation in the light of the dynamic classification of ground, adopted in the navigation maps, these data afforded a means of compiling a distribution map for bottom sediments, depending on bottom relief. The M. Lomonosov data, after its appropriate processing, will make it possible to refine this map. However, it is obvious even now, after a study of the mechanical composition with the microscope, that the distribution of sediment by mechanical composition is affected by the relief at any depth.

A microscopic study of material in suspension corroborates the fact that clastic material goes into suspension as the result of turbidity along submarine slopes, while its distribution shows, as do the mechanical composition data, that hydrodynamic activity is high at all oceanic depths, including those over 4000 m. Water movements, whatever their cause, do not cease (with depth), which is conclusive proof of the impossibility of burial of products of radioactive decay on the sea bottom.

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The Oceanology Institute,
Academy of Sciences, U. S. S. R.,
Moscow

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COPROLITES AND THE TRACKS OF BORING ORGANISMS: THEIR VALUE FOR A LITHOLOGIST[3]

by

V. P. Maslov

Some time ago I attempted to solve some problems often confronting a lithologist in his microscopic study of limestone [2]. This article is a development of the same topic.

This article is based on the results of study of numerous thin sections sent in by many lithologists. Particularly interesting were those from beds of Tertiary age of Ferghana, which have provided the bulk of data. I take this opportunity to express my gratitude to lithologists I. M. Arkhangel'skaya, O. I. Zelenova, and N. A. Kondrat'yeva, for the loan of their material.

TRACKS OF BORING ORGANISMS

Tracks of fossil "Boring algae" have been frequently described in the Soviet and foreign literature. J. Pia has given them a general name of Palaeachlya. They are not particularly noteworthy, except for indicating very shallow conditions. Under the present conditions they often penetrate and live in mollusk shells in the beach sand periodically wetted by the sea. These algae may interest a lithologist but they have no stratigraphic value.

L. Callier noted, in his time, that oölites are bored through by Girvanella algae. We deal here, most likely, with an organism similar to Girvanella rather than with Girvanella itself, because no one, except L. Callier, has assigned it to the category of boring organisms. So far as we are concerned, the participation of algae in boring through oölites is the important fact. I have observed in the Ferghana Tertiary beds numerous oölites with light-colored concentric layers intersected by dark radial, rectilinear, thin to thick bands (channels?). These bands may narrow down toward the center (cones) or maintain their thickness (cylinders), quite distinct against the light background, and terminate at the inner central nucleus (usually a shell fragment). The origin of these radial bands remained obscure. However, the situation became clear when an oölite was observed in which the central nucleus had obviously been bored through.

This oölite, somewhat elongated and with a rounded shell fragment in its center, is pierced

[3]Koprolity i sledy sverlyashchikh organizmov-ikh znacheniye dlya litologa.

by dark and thick radial channels terminating mostly at a shell fragment (Figure 1, 4). The fragment is covered by a dark carbonate crust. Some of the radial cylinders or channels, particularly the thicker ones, are filled with dark pelitomorphic carbonate and continue into the central fragment, all the way across it. This suggests that 1) the dark radial cylindrical and conical tracks in oölites may be channels, younger than the oölites themselves; 2) they are tracks of boring organisms, made perpendicular to the oölite layers and its surface, as has been observed in some shells; 3) under appropriate conditions, these borers penetrated the nucleus itself; and 4) the dark pelitomorphic material within the tracks is ooze which has penetrated the hollows left behind by the dead borers.

In this example, we have nothing to go by in deciding whether these borers were algae or animals. It is obvious that they were endowed by the capacity of selectivity: they settled down only in oölites and bored through only some of their organic nuclei (gastropods?). Such a selective capacity has been demonstrated by algae boring through calcareous shells. They usually settled on the pelecypod shells and less commonly on fragments of other organisms. This may be due to the shell structure and its resistance to destruction, different for different calcareous organisms. Incidentally, such differences are expressed in the rate of dissolution and in the recrystallization of detritus.

In this particular example, the boring organism preferred the oölite carbonate to that of the shell.

What has been said above is not intended to describe unknown and unpreserved organisms but rather to draw attention to the origin of the radial structure in oölites, those dark radial bands which may also have some other explanation.

"PSEUDOALGAE" — COPROLITES

Fossil microcoprolites have not been given much attention in Russian literature. Only a few lithologic works contain descriptions of coprolitic, coprogenic, limestones.

I. V. Khvorova [3], in her study of the interior of worm tracks, demonstrates a coprolitic origin for the rounded and oval crumbs; she recognizes two varieties of coprolitic limestones: 1) consisting of small calcareous crumbs with a rough surface and carrying fragments of organisms; and 2) represented by smooth, apparently displaced, round to oval calcareous crumbs.

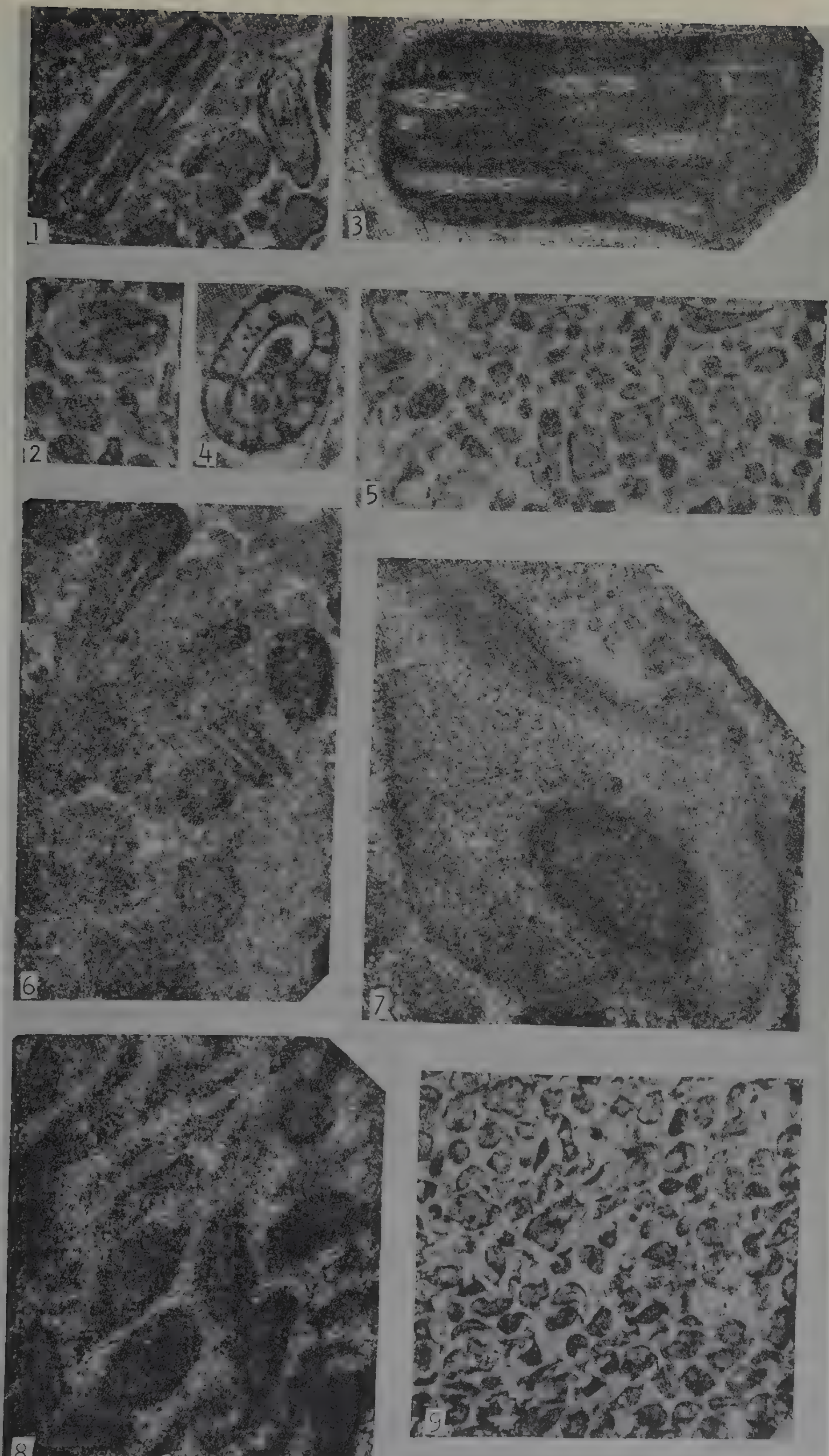
Despite her painstaking description of rocks, no diagnostic features for coprolites as such are mentioned. Now it may not always be possible for a lithologist to observe the tracks of organisms in rock; more often than not, they are invisible, inasmuch as the entire rock consists of coprolites. For that reason, the microscopic study of coprolites and the opportunity for identifying them in a thin section are of special importance. G. I. Bushinskiy [1] believes that many phosphorite beds are coprolitic. He presents photographs of them as well as sketches of present-day coprolites, after Moore.

Working on the Tertiary of the Vakhsh River and the Stalinabad area, I. M. Arkhangel'skaya came across some formations which, at first glance, may be taken for Siphonales remains. They are dark, non-transparent cylindrical fragments with fine longitudinal internal light streaks (channels?) which do not reach to the formation surface. I identify them as animal feces.

These light-streaked coprolites have a history of study of their own. E. Joukovsky and J. Favre [10] described them as "Organism B". Later on, E. Paréjas [12, 13] assigned them to coprolite Thalassinida (Coprolitus salevensis Parejas). A. Carozzi [6] concurred with him after having found them in the Jurassic of Switzerland. J. Cuviller [7, 8] first believed them to be remains of Characaceae, then concurred with E. Paréjas and agreed that the formations he had observed in the Aquitanian and Neocomian were feces of crustaceans, specifically Estheria, whose shells they accompany. These coprolites have been observed in deposits from Lower Liassic to Oligocene, in France, Morocco, and Anatolia. J. Cuviller believes that beds containing these coprolites may serve as local "markers" but not as age indicators.

FIGURE 1. Coprolite formations

1 - coprolite with longitudinal light streaks: to the right, axial section; to the left transverse section; coprolite to the right encloses a foraminifera; thin section 966; Chil'dara village, Alay stage; 20 X; 2 - same in transverse section; thin section 612; Alay stage; Pankun village, 20 X; 3 - same in a longitudinal section; thin section 544; Khazyr-Khana village; Alay stage; 20 X; 4 - oölite with channels left by borers; Tertiary of Fergana; 30 X; 5 - coprolitic limestone with coprolites of various forms and sizes; Vakhsh River; Bokhara stage; thin section 392; 20 X; 6 - coprolitic limestone with assorted coprolites, the darker ones having light longitudinal streaks; thin section 15; Kuruk village; Alay stage; 20 X; 7 - complex coprolite with elongated ends and an "elliptical" nucleus; thin section 163; Kuruk village; Alay stage; 90 X; 8 - "tailed" coprolites in Ordovician limestone, Podkamennaya Tunguska; 10 X.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Recently, P. Bronnimann [5] has described the same problematic formations under the generic name Favrenia Bronnim., comprising two species, F. joukovskiy Bronnim. and F. cuvilleri Bronnim, differing in the diameter of their light streaks. Without sharing the view of E. Paréjas and J. Cuviller on these organisms, as coprolites, P. Bronnimann offers no explanation of his own; he believes them to be Jurassic to Lower Cretaceous fossils, although they are known from the Oligocene of Morocco, Anatolia, and France.

According to I. M. Arkhangel'skaya, these coprolites are very common among coprolites of other forms from the Bokhara and Alai "stages" in the area of Vakhsha River and Stalinabad. They are as dense as the other coprolites (Figure 1, 1 and 2) or denser and darker (Figure 1, 6). They are irregularly cylindrical to truncated-conical, somewhat tapering off toward the ends. Their axial sections show thin, straight light streaks of variable thickness. The transverse sections show irregularly rounded and uneven outlines and haphazardly distributed light dots (Figure 1, 2). Seen under a high magnification (90 X, Figure 1, 3), these coprolites show a heterogeneous carbonate groundmass, more compact about those light streaks which are not connected with the outside. The dark pelitomorphic carbonate contains lighter-colored small fragments, haphazardly distributed. The coprolite ends are either truncated or slightly rounded.

As we have seen, the latest hypothesis on the origin of coprolites is related to the life activity of crustaceans. Whether this is so is difficult to say; it is certain, however, that they contain calcareous ooze. The light streaks or "channels" within them may be explained as fragments of some organic sinews, rotted away and disappeared in fossilization. That, however, remains to be demonstrated.

The composite (in their internal structure) coprolites usually enclose extraneous objects (foraminifera, echinoid fragments, other coprolites, sponge spicules, etc.). They vary in density and transparency. Apparently, that does not depend solely on the mud-eater and the reworked material but also on the preservation of a coprolite, its recrystallization, etc. It is often difficult to tell coprolites from bottom detritus reworked by enveloping and borer algae.

Figure 1, 7 illustrates a definite coprolite, irregularly lenticular, with another coprolite, dark and elliptical and pebble-like, within it. In this example the flattened and elongated end of this composite specimen, with a different density and grain size of its carbonate suggests its coprolitic origin.

The "tailed" coprolites are fairly common in the Paleogene of central Asia, as well. They are lenticular bodies with constrictions often uniting two adjacent coprolites. In some cases the entire rock body is made up of such irregular coprolites (Figure 2, 8).

The "tailed" coprolites are formed when a large mud-eater passes oölites through its intestines; in this process, the oölite is split across, its surface is reworked by chemical reagents, and is enveloped with a slimy mass which form the "tails" on the two halves (Figure 1, 8). These forms, which I have previously names "oölitic coprolites" [2], appear to have been mistaken for "algae"[4] by earlier investigators, which is quite understandable since oncolites often do not show any distinctive features and are readily altered by epigenetic processes (Figure 2).

Simple homogeneous coprolites are most common and have a variable form, often elongated. They have been described by some investigators (e. g., Gürich, as Stercome). Many thin sections exhibit a mass of small crumbs of pelitomorphic carbonate in assorted shapes, more or less rounded. Some of these crumbs carry fine sediment and very fine sand grains of variable density. Even the adjacent coprolites often have a different density, which points to their primary differences (Figure 1, 5).

The form of coprolites is variable and not always rounded to cylindrical; they may be lenticular, elongated in one or two directions, bent, and apparently corroded. In such examples, a coprolitic origin is difficult to demonstrate. It is quite probable that some micro-oncolites are true coprolites, inasmuch as coprolites of a complex composition undoubtedly do exist. Apparently, the only feature definitely foreign to true coprolites is a stratified structure (with the exception of reworked oölites). A typical and distinctive feature of coprolites, which sets them apart from other formations, is the slight tapering off toward one end, in both the cylindrical and elliptical forms.

The nearly round coprolites commonly have a short "tail" at one end, representing a squeezed-off segment, often quite small.

All these details set coprolites apart from inorganic pebbles.

The internal structure of coprolites, too, has distinctive features of its own, quite

[4]Unexplainable forms are often designated as "algae", without any analysis of their structure and any proof, simply in order to say something about their origin.

FIGURE 2. "Oölitic coprolites", a diagrammatic representation of Permian oölites from the Ural region, reworked by mud eaters (worms?).

conspicuous in composite coprolites. While a common limestone pebble is homogeneous throughout (as if carved out of rock), a coprolite always has a fringe of dark pelitomorphic carbonate, without any addition of material at its middle. As we have seen, channels in the original Fergana coprolites do not reach the surface, because their ends are enveloped by aphanitic material.

Coprolites are often reminiscent of pebbles and sand grains, especially when they include grains of dolomite. As a rule, however, as suggested before, the dolomite crystals are "concentrated" in the middle part, without entering the coprolite itself.

Further study will clarify our ideas on coprolites; this communication is but an outline of the problem.

What is the origin of a calcareous coprolite? Undoubtedly, it is related to a reworking of calcareous ooze by mud-eating organisms; in this process, all sorts of material were assimilated and reworked, partly mechanically but mostly chemically, to extract its organic content. It is reasonable to suppose that carbonate (less commonly, non-carbonate) particles were altered, being acted upon by chemical reagents in the intestinal tract of the mud-eater. It is possible that such alterations are expressed in a darkening of the surface of coarser fragments, in the vagueness of the foraminiferal tests, the "pelitization" and granulation of the echinoid fragments, etc., quite often observed in limestones of all ages. The diversity of forms, structures, and sizes of calcareous coprolites should be ascribed to the diversity of mud-eaters. At this stage of our knowledge, we are lost in this diversity. In the future undoubtedly many more than our three types of coprolites, and a number of subtypes, will be discovered. It is possible that many of them will acquire a stratigraphic value, because many mud-eaters have died out in the course of the geologic history of the earth.

It should be emphasized that the study of coprolites will reduce the role of "boring algae" which are supposed to be able to alter the bottom detritus and which indeed do in some instances penetrate the shell fragments. For example, the alterations in Stafella of the Uralian upper Paleozoic to a point where they become vague lumps which I believed to be the result of thier reworking by boring organisms, may be explained by their being reworked in the intestines of borer animals.[5] However, the latter lived at different depths; for that reason, coprolites as such are not a criterion of depth. On the other hand, blue-green boring algae inhabit shallow depths and are indicators of such conditions. Thus, the determination of causes for the alteration in detritus affects the final conclusions.

Inasmuch as the reworking of ooze by mud-eaters may be either partial or complete, there arises the problem of the textural nomenclature of limestones. An originally foraminiferal ooze may be reworked to such an extent that the final product should be called "foraminiferal-coprolitic limestone". The same goes for organisms, with the primary material name preceding the term, "coprolitic", such as "algal-coprolitic" limestones. Finally, reworked oölitic limestones with relicts of the oölitic texture, may be called "oölitic coprolitic". It may be that the popular term, "pseudo-oölitic limestone", includes a number of coprogenic rocks; that, however, must be demonstrated in each specific case. Some oncolites of the Osaqia type, without a definite concentric structure, too, may be regarded as coprolites, particularly those forms with pointed ends or lenticular in section.

Coprolites are rock-forming elements in Paleogene limestones of Fergana as well as in limestones of other ages. Forming crumbs similar in size to fine or coarse sand grains, they are readily transportable and mechanically deposited. Mostly, however, they are formed in situ. At times, when not all of the rock is made up of coprolites, the tracks of mud-eaters are visible, but in most places the rock has been reworked and presents a homogeneous coprolitic mass.

The study of coprolites has just begun (macrocoprolites have been studied, but mostly externally, [4]). A lithologic study of rocks from this point of view may lead to interesting results.

This communication does not pretend to solve all problems; it merely clarifies to a certain extent the role of the above-described fossils and poses for future investigators a problem for further study of these often little understood

[5]In this connection, it is pertinent to consider the problem of "corrosion" of the surface of organic fragments by acids in the intestinal tracks of mud-eaters.

but nonetheless interesting forms, important for an understanding of the origin of limestone.

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Geological Institute, Academy of Sciences, U. S. S. R., Moscow

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ABSOLUTE AGE OF VOLCANIC FORMATIONS IN THE BADZHAL'SK AND BUREINSK RANGES[6]

by

Ye. V. Bykovskaya and N. I. Polevaya

An earlier attempt to determine the absolute age of extrusive rocks by the argon method [4] brought encouraging results. Studied at that time were specimens of different ages, textures, and composition, taken mostly from different regions, with unknown age relationships, and by far not always dated biostratigraphically.

Our work is an attempt to fill up this gap by selecting an area with considerable development of volcanic formations of different ages, fairly well dated. The selection of the upper Bureinsk region was not accidental. Specimens of extrusive rocks were collected in the basins of Suluk, Amguna, and Urma rivers (see map, Figure 1), from paleontologically dated stratigraphic divisions or from other stratigraphic intervals whose sequence had been reliably established.

This sequence of Mesozoic deposits in the Badzhal'sk and Bureinsk Ranges is diagrammatically presented in a stratigraphic column (Figure 2) compiled by Ye. V. Bykovskaya and R. I. Sokolov on the basis of their personal observations and from information from earlier investigators (A. A. Golovneva, M. I. Itsikson, L. B. Krivitskaya, E. L. Shkol'nik, and others).

Black dots in Figure 2 show the stratigraphic position of samples analyzed; also given are the composition of volcanic rocks and the paleontologic basis for the dating of some intervals of this sequence.

The oldest volcanic formations in the area are acid extrusives (see Table, specimens 20 and 1) and tuff along the right bank of Suluk River and the Chert (Devil) River basin. They are marked by considerable disturbances (dips steeper than 35 to 40°, as a rule), a well-developed cleavage, the compact nature of the

[6] Absolyutnyy vozrast vulkanogennykh obrazovaniy Badzhal'skogo i Bureinskogo khrebtov.

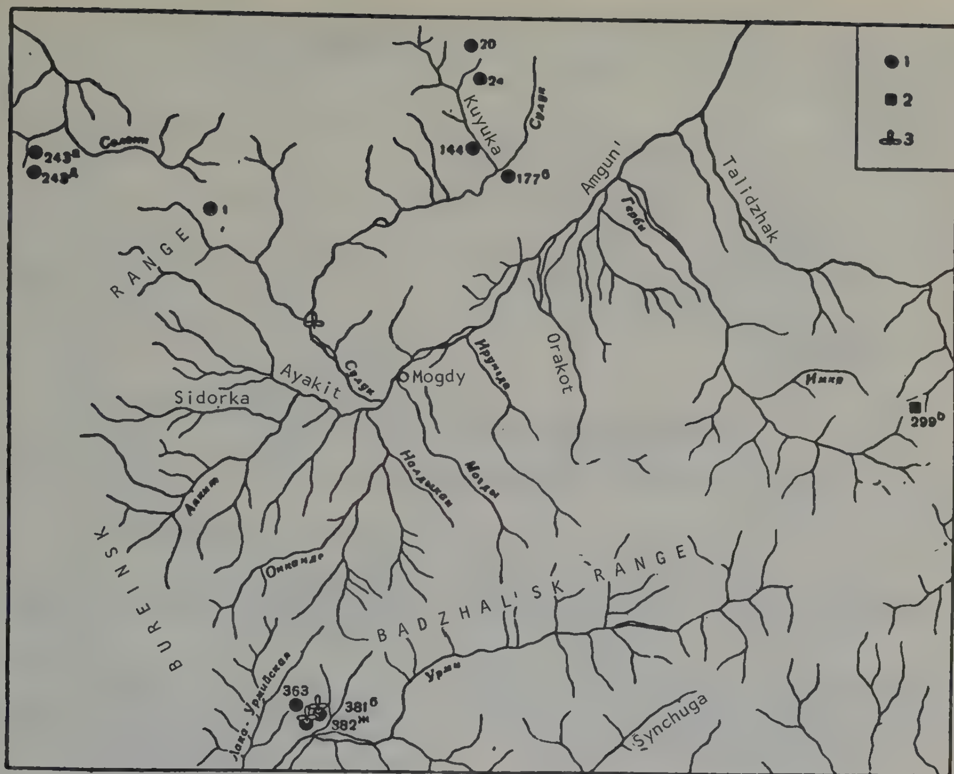

FIGURE 1. Index map of the distribution of specimens

1 - extrusives and tuff; 2 - granite; 3 - flora collecting localities.

tuff, and conspicuous diagenesis. This sequence is 800 to 900 m thick.

Conglomerate and polymictic sandstone occur at the base of the overlying sedimentary deposits in the Soloni River basin, whose Jurassic age has been definitely established from fossils (Figure 2; identified by N. S. Voronets and G. Ya. Krymgol'ts).

About one third of the clastic material in the conglomerate and sandstone consists of extrusives and tuff similar in composition to the above-named volcanics from the right banks of Sulak and Chert rivers. The age of quartz porphyry pebbles (Specimens 243-a and 243-e) of these rocks was determined.

The next manifestation of volcanic activity in this area took place in the Early Cretaceous. This is demonstrated not only by the presence of tuffaceous material in sedimentary deposits of the Urmi and Laki-Urmiyskaya watershed but by porphyrite and tuff as well. The total thickness of this sequence is 500 to 700 m. Its Lower Cretaceous age has been determined by V. A. Samylina from fossils collected by Ye. V. Bykovskaya and R. I. Sokolov in sedimentary rocks along Cholgachi-Makit River. We determined the age of porphyrite (Specimen 363), its tuff (Specimen 382-j), and porphyrite from a pebble in interformational Lower Cretaceous conglomerate (Specimen 381-b).

Higher up there is a sequence of dacite porphyry, plagioporphyry, and quartz porphyry (Specimen 219), tuff and tuffolava with intercalations of tuffite-sedimentary rocks. Its thickness is 600 m. It has been tentatively assigned to a Lower to Upper Cretaceous interval.

There is no weighty evidence for assigning this sequence to either. There are only rare spores in tuffaceous shale (Figure 2), collected by A. A. Golovneva [2] in the Talidzhak basin and identified as Upper Cretaceous by A. I. Myachina.

In the Gerbi River basin, this sequence is overlain by quartz porphyrite, lava breccia, and tuff, with a total thickness of about 500 km. A direct occurrence on them of acid extrusives of the same thickness, represented by coarse quartz porphyry (Specimen 24), liparite-dacite (Specimen 144), and tuff has been noted on many

Division	Absolute age in million yr	Stratigraphic column	Specimen No.	Composition	Paleontologic basis for dating
	74		177б	Spherulitic liparite and felsoliparite, vitroliparite, motley tuff and tuffaceous lava	
Cr_2	86 93 91		299б 144 24	Coarse quartz porphyry, liparite-dacite, less common tuffs	
				Quartz porphyrite, lava breccia, tuff, less common tuffaceous lava	
Cr_{1-2}?	105		219	Dacite porphyry, plagioporphyry, less common quartz porphyry, their tuff and tuffaceous lava with horizons and lenses of tuffaceous and siliceous rocks, siltstone and sandstone	Polipodiacea sp., Osmunda sp. Podocarpus sp., Picea sp., Pinus nogpoga Haploxylon, Alnus sp., Juglans sp. Betula sp., Quercus sp.
Cr_1	122 115 115		363 382ж 381б	Conglomerate, sandstone, siltstone with tuffaceous material; porphyrite and tuff	Gleichenites sp., Elatocladus manshurica (Vok) Yabe, Cyparissidium sp., Coniopteris onychioides var. et Kam., Onychiopsis psilotoides (St. et Webb), Ward cladophlebis sp., Pityophyllum nordenskioldii (Heer) Nath.
J_1-J_3	180 164		243а 243д	Conglomerate containing extrusive pebbles (samples 243-a, 243-e); arkosic sandstone, siltstone, shale	Oxynoticeras sp., Amaltheus margaritatus, Pseudolioceras sp., Grammoceras sp., Ludwigia sp., Arctocephalites sp., Cranocephalites sp.
T?	162 193		20 1	Quartz porphyry and porphyrite; tuff and tuffaceous lava	
Pz				Conglomerate, sandstone, marble	

FIGURE 2. Diagrammatic stratigraphic column of Mesozoic deposits of the Bureinsk and Badzhal'sk Ranges

occasions by investigators in the Urmi basin. In the same area, according to M. I. Itsikson, they are cut by the Urmi Massif granite; and by granite porphyry stocks (Specimen 299-b) in the basin of Imuk River, a right tributary of the Gerbi.

The Upper Cretaceous extrusive body is capped by felso- and vitroliparite (Specimen 177-b), spherulitic liparite, tuff, and tuffaceous lava, unconformable on the above-named volcanics and widely distributed in the Amgun-Suluka watershed. Results of the absolute-age determinations are presented in a table (page 69), in juxtaposition to their place in the stratigraphic section.

Absolute age of extrusive rocks in the Verkhne-Bureinsk region, determined by the argon method[1]

Nos.	Sample Nos.	Rocks	Location	K, %	$K^{40}\cdot 10^{-5}$ yr^{-1}	$Ar^{40}\cdot 10^{-7}$ yr^{-1}	$\frac{Ar^{40}}{K^{40}}$	Age in million yr.	Author	Geologic age
1	177-b	Vitroliparite	Left bank, Suluk River	1.48	0.178	0.077	0.0043	75	Ye. V. Bykovskaya	Upper Cretaceous
2	299-b	Granite porphyry	Talindzhak River basin	3.58	0.500	0.244	0.0049	86	A. A. Golovneva	
3	144	Liparite dacite	Left bank Kuyuk River, right tributary of Suluk River	258	0.309	0.165	0.0053	93	Ye. V. Bykovskaya	
4	24	Quartz porphyry	Left bank of Kuyuk River	2.87	0.344	0.178	0.0052	91	"	
5	219	Quartz porphyry	Badzhad River	2.83	0.340	0.203	0.0060	105	A. A. Golovneva	Lower (?) — Upper (?) Cretaceous
6	363	Porphyrite	The Urmi-Laki Urmiyskaya watershed	1.03	0.123	0.086	0.0070	122	Ye. V. Bykovskaya	
7	382-j	Porphyrite tuff	"	0.76	0.091	0.060	0.0066	115	Ye. V. Bykovskaya	Lower Cretaceous
8	381-b	Porphyrite pebble from interformational conglomerate	"	1.22	0.146	0.097	0.0066	115	Ye. V. Bykovskaya	"
9	243-a	Quartz porphyry pebble	Left bank, Soloni River	3.45	0.415	0.430	0.0103	177	"	Umal'tinsk formation,
10	243-e	"	"	3.79	0.455	0.431	0.0095	164	"	Lower Jurassic (conglomerates)
11	20	Quartz porphyrite	Left bank, Kuyuk River	2.31	0.277	0.261	0.0094	162	"	
12	1	"	Suluk basin, headwaters Chert River	2.72	0.326	0.371	0.0113	193[2]	L.M. Alekseyev	Triassic (?)

[1]Given for correlation are data for a sample of granite porphyry which cuts the Upper Cretaceous extrusives.
[2]No isotope analysis of liberated argon was done for this sample; for this reason, its true age should be somewhat lower.

All but three of the samples analyzed were collected and petrographically studied by one of the authors. Specimens 219 and 299-b were kindly loaned by A. A. Golovneva; Specimen 1, by L. A. Alekseyev. All samples were quite fresh and well preserved. Their potassium content was determined by L. V. Shashukova, by the dipicrylaminate method. G. A. Murina and V. D. Sprintson determined the traces of argon, by the volumetric method. The isotope analysis of argon was done by A. V. Mattes; in all analyses (except for specimen 1) a correction was made for the air argon.

The most precise constants now in use in most foreign laboratories were used in the age determination:

$\lambda_k = 0.557\cdot 10^{-10}$ yr^{-1} and $\lambda_\beta = 4.72\cdot 10^{-10}$ yr^{-1}[7]

In considering the age figures tabulated below, it should be kept in mind that the age given in previous publications by one of the authors [4, 5, 6, 7] on the Far East rocks has

[7]Reasons for the changeover to new constants are given by E.K. Gerling [3] after a critical examination of earlier experimental data and works by G. Wetherill, G. Wasserburg, et al [8].

been computed with old decay constants differing from the new ones by about 8 or 10%. Recomputed with the new constants, the age of those rocks (the Maritime Province Mesozoic-Cenozoic) will be older by about 8 or 10%. Conspicuous in the age determination results for extrusive rocks from the region of the Badzhal'sk and Bureinsk Ranges is an increase in the Ar^{40}/K^{40} ratio, with increased age, despite the differences between the analyzed rocks in both their structure and composition (vitroliparite, liparite-dacite, quartz porphyry and porphyrites). The potassium content in samples ranges appreciably, from 0.76 to 3.79%.

Of definite interest are data obtained on pebbles from conglomerates: they point to a fair preservation of their radiogenic argon. It appears that the determination of age of conglomerate pebbles, both extrusive and intrusive, may be quite useful in solving some geologic problems. Similar results were obtained by A. Ya. Krylov [3] who likewise did not find any substantial losses in radiogenic argon from pebbles of the Tien-Shan Caledonian granite.

Of interest also is the agreement in results obtained for granite samples (86 million years), the liparite-dacite cut by the granite (93 million years), and the overlying vitroliparite-dacite (75 million years). In any event, these figures suggest about the same very small losses in radiogenic argon, for both the granite and extrusives; this allows a correlation of ages as obtained for intrusive and extrusive rocks. We are aware of the fact that the data so obtained are quite inadequate for determining the age boundaries for stratigraphic divisions. However, the possibility of correlating volcanic sequences by the argon method cannot be questioned.

These age figures for Mesozoic extrusive rocks demonstrate the great potential of the argon method, particularly as a means of absolute dating of fresh and unaltered extrusive rocks.

As a matter of fact, this method is the only radiologic method which affords a means of successful age differentiation for the Mesozoic and lower Canozoic. The work in this field is being continued on stratigraphic sections of volcanic rocks in this area as well as in the north, central, and south Sikhote-Alin.

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The All-Union Geological Scientific Research Institute, Leningrad

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METHODS OF STUDY

SOME FEATURES OF QUARTZ-FELDSPAR SEPARATION USING MODEL "T" ELECTROSTATIC SEPARATOR[1]

by

I. P. Druzhinin

The problem of isolating a monomineral rock fraction from clastic rocks, for the purpose of detailed laboratory study, is one of the most labor-consuming procedures in lithologic laboratories. Among the fairly well mastered and widely used separation methods calling for a number of special techniques is the separation of minerals by their specific weight and magnetic sensitivity. In recent years, a number of new practical methods have been suggested. For example, Ye. V. Rozhkova and O. V. Shcherbak [6] of the All-Union Institute for Mineral Raw Material have proposed a method of electrochemical separation of minerals with a mercury cathode; Ye. V. Rozhkova and L. V. Proskurovskiy [6] a method of separating minerals by their dielectric permeabilities; and A. G. Kots and Ye. V. Rozhkova, a centrifugal separation method for minerals using, adhesive surfaces.

Members of the Geological Institute, Academy of Sciences Georgian S. S. R., M. M. Rubinshteyn, I. G. Grigor'yev, O. Ya. Gel'man, A. A. Khutsaidze, and B. T. Chikvaidze [7] proposed a composite method of separating monomineral fractions, glauconite and biotite, from clastic rocks, by means of electrostatic and electromagnetic separators.

The first domestic electrostatic laboratory separator (Model T) was built in 1956, by members of the All-Union Institute of Exploration Geophysics (VIRG). Its purpose was to separate titanium-bearing minerals (ilmenite, rutile). It has passed laboratory tests of enriching these minerals from natural mixtures such as occur in many ore deposits of the Soviet Union.

Application of the methods mentioned above opens up great possibilities in the field of beneficiation of various mineral mixtures. The study of beneficiation conditions and methods of obtaining pure monomineral fractions from mixtures of quartz and feldspar or of two feldspars is of considerable interest in this respect. Separation of such mixtures is quite a laborious process because of the slight difference in physical properties, i. e., specific weight, magnetic sensibility, dielectric permeability, and other parameters.

A distinctive feature of the electrostatic enrichment method is that it utilizes a group of physical phenomena, whose specific combination brings about satisfactory qualitative and quantitative separation results. This not only complicates considerably the control of differentiation for mineral mixtures but also necessitates a comprehensive study of many physical phenomena associated with the mineral fragments themselves, dielectrics, and semi-conductors, and conductors. The most effective phenomena affecting the process of electrostatic separation is the means of communicating electric charges to mineral particles, their electroconductivity, dielectric permeability, the contact difference in potential, pyro- and triboelectric effects, polarization phenomena in mineral particles, their form, moisture content, the degree of surface cleanliness, and some other technologic factors. Many of these parameters depend in turn on temperature; the electroconductivity depends in addition on the presence of foreign inclusions in minerals, even a small amount of which may greatly modify electroconductivity.

In view of these features of the electrostatic separation process, and considering the results of beneficiation already obtained for the dielectric group minerals, it was deemed expedient to carry on all experiments in beneficiating the quartz-feldspar mixtures on the electrostatic separator (Model T). Accordingly, 0. 1 to 0. 25 mm fractions of quartz and feldspars — albite, oligoclase, labradorite, and microcline were

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[1] O nekotorykh osobennostyakh separatsii kvartsa i polevykh shpatov na elektrostaticheskom separatore "T".

prepared. They were used in making working mixtures: quartz-feldspar (e. g., quartz-albite, quartz-microcline) and two feldspars. Each mixture was separated under an appropriate set of conditions, which should be regarded as the optimum. Of considerable interest is the beneficiation of an albite-microcline mixture, wherein a monomineral albite fraction was obtained.

Without getting into the design details of Model T and the operation of its radiotechnical setup, we shall consider the differentiation chamber (Figure 1) which consists of the following units: 1) feeder device (bunker, pans, and a

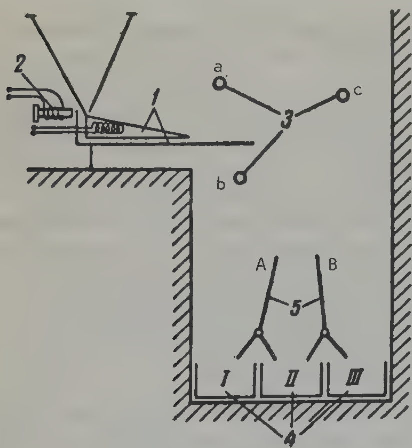

FIGURE 1.

helical device to change the inclination of the pans); a coil is mounted in the upper pan, allowing the mineral mixture to dry out before differentiation; 2) vibrator (electromagnet with a regulator); 3) high tension, round electrodes which set up a heterogeneous electrostatic field between themselves, the pan, and dischargers with the earth's potential; 4) receivers I, II, and III; 5) separators A and B for a qualitative differentiation of the stream of granular material.

The disposition of the lines of force in the electrostatic field, as well as its potential, can be altered by changing the electrodes' position, polarity, and potential, up to 15 kilovolts. The working position of the electrodes is selected in such a way as to fully eliminate the chance of a spark discharge in the process of separation.

It is known that each particle, moving through an electrostatic field in the process of beneficiation, is acted upon by different electrical forces, including the ponderomotive field forces. F. Fraass and O. Ralston [8], along with other investigators [2], believe that the ponderomotive forces, brought about by the heterogeneous electrical field, are very small compared with electrical forces acting on the particle charge, even in a completely heterogeneous field, with the value of the ponderomotive force decreasing in proportion to the cube of the particle size. For these reasons, the ponderomotive force can be disregarded in all practical calculations of the electrostatic separation process in air. On the other hand, a considerable polarization of mineral particles has been observed in this process, both because of the electrostatic field and the pyroelectric effect; the triboelectric polarization phenomena were not sufficiently well expressed although the pan material was changed several times (steel, brass, cardboard, and celluloid were used).

The polarization of mineral particles was expressed in the acquisition of definite dipole moments substantially affecting the differentiation of mixtures (Tables 1 and 2). Thus Table 2 shows the separation results for mixture microcline-albite (II, III), when a pure monomineral albite fraction was obtained without heating up the pan.

The drying out of the mineral mixtures, prior to separation, stabilizes the moisture content in the particles; in addition, it brings about some degree of pyroelectric polarization which, in its turn, either strengthens or weakens the polarization effect of the electrostatic field. This feature of the polarization of mineral particles is particularly conspicuous as the effect of the electrostatic polarization increases. This polarization is reflected in the grouping of particles according to their polarity, and is accompanied by the formation of peculiar dendritic pine branch patterns at the loci of the most intensive changes in the potential gradient of the electrostatic field, as happens at the pan edges. The loosening of such aggregates from the pan, and their movement toward the differentiation chamber, have never ended in desirable separation results. On the contrary, the initiation of such dipole aggregates indicated the necessity for reducing the degree of polarization in mineral particles.

Our observations of the formation of that peculier fan of mineral particles in an electrostatic field have shown that such phenomena occur first of all because of the formation of electric charges on the particles, while the presence of the definite dipole moments on the particles creates conditions necessary for their orientation along the field lines of force.

The experiment with enrichment of quartz-feldspar mixtures demonstrates that out of all the physical parameters which control the separation results, the phenomena of charging and polarization in mineral particles are of paramount importance. A detailed study of these phenomena for a given group of minerals will promote a successful solution of practical

Table 1

Granular material	Fraction mm	Angle of inclination of pan, 0° / vibration regimen for pan, B	Angle of inclination for separators A and B, 0°	Potential on electrodes, kilovolts a	b	c	Degree of separation, by receivers, in % I	II	III	Regimen of pan heating	Remarks
Quartz-microcline	0.1—0.25	11/30	104/80	—5	+10	—5	> 98 microcl.	Few remains of mixture	> 98 quartz	80	Without rerun
Quartz-albite	0.1—0.25	11/35	100/84	—4	+6.5	—4	> 90 albite	Remains of mixture	> 90 quartz	80	After 2-3 runs
Quartz-labradorite	0.1—0.25	11/30	95/72,5	—5.5	+11.5	—5.5	> 85 labradorite	"	> 95 quartz	80	
Quartz-oligoclase	0.1—0.25	11/30	94/80	—5	+9	—5	> 90 oligoclase	"	> 90 quartz	80	

Table 2

Granular material	Fraction mm	Angle of inclination of pan, 0° / vibration regimen for pan, B	Angle of inclination for separators A and B, 0°	Potential on electrod. kilovolts			Degree of separation, by receivers, in % I	II	III	Regimen of pan heating	Remarks
I. Microcl.-albite	0.1—0.25	11/20	100/109	—8	—8	+4	80 albite	Mixture	98 microcline	Cold	Obtained without rerun
II. "	0.1—0.25	11/20	96/82	—8	—8	+4	95 albite	"	75 microcline	80	
III. "	0.1—0.25	11/20	104/104	—8	—8	+4	100 albite	Mixture more enriched in microcline	Mixture less enriched in microcline	Cold	
Microcline-oligoclase	0.1—0.25	11/20	94/82	—8	—8	+4	98 oligoclase	Mixture	87 microcline	80	

problems. At the same time, it is necessary to study the nature of deviation of various particles, depending on the potential and configuration of an electrostatic field.

From the point of view of the mineralogist, the most interesting in this respect is the study of enrichment of a microcline ($KAl_2Si_3O_8$) — albite ($NaAl_2Si_3O_8$) mixture. This mineral pair is characterized by great similarity in their crystalline structures and by a number of other mineralogic features: both are light-colored, have a comparatively low refractive index, are comparatively hard (6 to 6.5); have a perfect cleavage along (010) and (001), intersecting at almost 90°; a low specific weight (albite, 2.624; microcline, 2.54 to 2.57), and the capacity for forming binary mixtures.

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Geological Institute,
Academy of Sciences, U. S. S. R.,
Moscow

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FLOTATION METHOD OF MEASURING THE SPECIFIC GRAVITY OF INDIVIDUAL MINERAL GRAINS[2]

by

M. Ya. Kats

A precise determination of specific gravity of mineral grains smaller than 1 to 0.5 mm is important in a number of mineral studies.

An analysis of the precision of the specific-gravity measurements of solids and fluids, as given in handbooks of physical and chemical constants, shows that specific gravity of pure solids (including crystalline, both compound and simple, down to the elements) is given to the first, second, rarely the third decimal, with the fourth rarely added [13]. Specific gravity of water is measured to the sixth decimal [6, 12].

It follows from these figures that in macroscopic volumes of solids, atoms and molecules are arranged on the whole less uniformly than in liquids; in crystals they occur in strictly regular lattice planes with definite parameters, while only an approximate order prevails in liquids. This is because the structural analytic methods (x-ray, electronographic) reveal the microstructure of a crystalline body but fail to register the numerous flaws, i. e., "disorders", in it; the order of these flaws may be several times

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[2] Flotatsionnyy metod izmereniya udel'nogo vesa otdel'nykh zeren mineralov.

smaller than the interplanar distances and they only affect the macroscopic characteristics of the crystalline body. The specific gravity of a mineral is the simplest macroscopic physical constant which by definition must be, roughly, a linear function of the concentration of some type of "disorder" in that mineral, such as a foreign inclusion (solid, liquid, and gaseous) or a flaw in its crystalline structure (a dislocation, microfracture, etc.). Such "disorders" may be substantially different in the same minerals formed under different conditions, at high and low temperature, in the presence of different additives, while growing in association with different minerals, etc.

The specific gravity of a given mineral is known to fluctuate within about 0.1 and over, within about 0.01 for pure varieties [2, 3, 4, 9]. A determination of regularities in these fluctuations for the same minerals of different origin can be done only by a mass method of specific gravity measurement, with an error at least one order lower.

A flotation method for specific gravity determination of individual mineral grains has been worked out in the Authigenic Mineralogy Laboratory, the Geological Institute, Academy of Sciences, U. S. S. R.; this method satisfies all these requirements. It has been tested on quartz and microcline grains, 0.1 mm and larger. Work on smaller grains is possible with a microscope.

The flotation analytic method is often used in most precise physiochemical investigations. For example, the specific gravity of water is determined to $\pm 3 \times 10^{-7}$, by means of a quartz float [12]. In a number of experiments, the flotation method was used in measuring the light potassium isotope concentration in KCl grains 1.5 x 2 mm [8].

The geologic literature contains many good manuals on measuring the specific gravity of individual minerals in heavy liquids, by the "sink or float" method. It is stated in the fundamental monograph by E. M. Bronshtedt-Kupletskaya [3, 4] that an accuracy of ± (0.002-0.003) has been obtained in very careful and apparently unique measurements by this method. V. P. Petrov believes [10] that by means of a microscope and a set of heavy liquids with specific gravity intervals of 0.02 to 0.03, reliable measurement of specific gravity of individual mineral grains is possible only down to ± (0.01-0.02). The Ye. V. Kopchenova text [9], written for wide distribution, states that an accuracy of ±0.05 can be attained by this method. The description of heavy liquid sets (NTZh-1 and NTZh-2) for determining specific gravity of minerals, exhibited at the All-Union Industrial Exposition by the Ministry of Geology and Mineral Conservation (1957), states that specific gravity is determined by this method down to ±0.1. Although E. M. Bronshtedt-Kupletskaya [3] cites the specific gravity - temperature relationship for some heavy liquids and indicates that "a change in the specific gravity of a liquid in order to keep the specimen 'in suspension' can be achieved by changing its temperature", the true possibilities of the flotation method in determining the specific gravity of individual mineral grains have not been investigated, as yet, and are not being taken advantage of by lithologists and mineralogists.

PRINCIPLE OF THE FLOTATION METHOD

The thermal coefficient of volumetric expansion of liquids is considerably greater than for solids. Some numerical data illustrating this are given in Table 1. This table shows that this coefficient is about 20 to 100 greater for heavy liquids than for minerals. To change the specific gravity of a liquid by about 0.1, it is sufficient to change its temperature by 40 to 60°; in that operation, the specific gravity of a mineral changes but by about 0.001, which is readily accounted for, when necessary.

If the specific gravity of a given mineral grain be measured roughly, down to ±0.1, a liquid can be selected in such a way as to have the density of the mineral between the two extreme values of its own density, in the working temperature range (see below). When placed in such a liquid, a grain will float at the lower temperature, and sink at the higher. By measuring the flotation temperature of the grain at its equilibrium position in the liquid, and with the temperature-specific gravity relationship of the fluid known, the specific gravity of the grain can be determined. When the grain density ρ_2 is close to that of the liquid, ρ_1, the grain motion in the liquid will be laminar, and its velocity can be determined from the Stokes law for the motion of a sphere in a liquid:

$$V = \frac{2}{9}\,\frac{r^2(\rho_2 - \rho_1)}{\eta}\,g,$$

where r is radius of the sphere; g is the acceleration of gravity; η is viscosity of the liquid. In this formula, the ratio $(\rho_2-\rho_1)/\eta$ along is dependent on temperature. The difference in densities, $\rho_2-\rho_1$, increases linearly with temperature (Figure 1); the liquid's viscosity decreases in proportion to the temperature increase, within a narrow range (5 to 10°C) [5]. Consequently, the ratio $(\rho_2-\rho_1)/\eta$, in the general case, will be a quadratic function of temperature. However, an analysis of numerical factors shows that, for a narrow temperature range, the quadratic item can be disregarded because its factor is 10 to 100 times smaller than the linear term factor. As a result, the velocity of a grain, within a narrow temperature range, will change linearly with temperature T of the liquid, in accordance with

Table 1

Medium	Thermal coefficient of volumetric expansion $\beta \times 10^5$	Change in specific gravity at temp. change from 10 to 70°C
Crystalline quartz	3.6	0.005*
Hornblende	1.6	0.002*
Zircon	0.7	0.001*
Marble	2.1±0.6	0.003±0.001*
Water	~ 30	~0.02**
Ethyl alcohol	110	~0.06**
Bromoform	95	~0.15
Mixture bromoform-alcohol (3.67% by weight)	100	~0.15
Thoulet solution	54	~0.1
Mixture, Thoulet solution and water (3.73% by vol.)	50	~0.09
Clerici's solution	38	~0.1
Mixture, Clerici's solution and water (2% by weight)	41	~0.1

*After F. Birch, J. Sharer, and H. Spicer [1].
**After D. Kay and T. Libby [7].

the Stokes formula. On the other hand, at the flotation temperature T_f, the velocity of the grain will be zero. Accordingly, the temperature — velocity formula will be as follows:

$$V = C(T_\Phi - T),$$

where C is constant. This formula is the theoretical basis for our method of determining the flotation temperature. The velocity of the grain is determined from its upward and downward movements at different temperatures of the liquid. Taking the upward movement as positive and the downward as negative, a velocity-temperature graph may be constructed. It should be a straight line. Its point of intersection with the temperature axis is the flotation temperature for the given grain and fluid. It is quite obvious that any procedure previously used in the "sink or float" method to put a grain "in suspension" and directly to observe it exactly at zero velocity will produce much cruder results in determining the specific gravity of grains in heavy liquids.

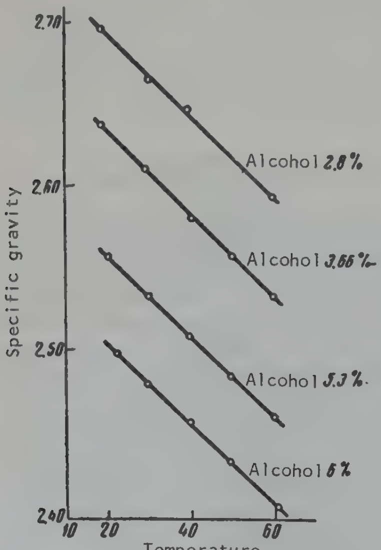

FIGURE 1. Temperature relationship of specific gravities of bromoform and alcohol (% by weight)

A CONTINUOUS SERIES OF SPECIFIC GRAVITIES FOR HEAVY LIQUIDS

In measuring specific gravities up to about 4.1, for mineral grains by the flotation method, use was made of bromoform-alcohol mixtures and of the Thoulet and Clerici solution and water. Bromoform and its five alcohol mixtures afforded a means of obtaining a continuous series of specific gravities, from about 2.4 to about 2.9, in a temperature interval from 15 to 65°C; the Thoulet solution and its three mixtures with water produced the respective figures of 2.85 and 3.2 for the 10 to 70°C temperature interval; and the Clerici solution, 3.8 to 4.1, and 10 to 70°C. In that way, it has been experimentally demonstrated that by using bromoform and Thoulet's solution, it is possible to obtain a set of fluids with specific gravity intervals of 0.1, so that by changing their temperature from about 10° to about 70°C a continuous series of specific gravities is obtained, ranging from about 0.8 to about 4.1.

The specific gravity of fluids was determined with two 50 cc standard glass pycnometers. Their temperature was maintained constant, down to ±0. 1° C, with a TS-15M ultrathermostat. Results of measurement for bromoform-alcohol mixtures are given in Figure 1. Each point represents the average of two independent measurements. An analysis of the numerical results of these measurements shows that the mean error of this method is ±0. 0005; this is the precision with which it is possible to determine the specific gravity of a fluid from the graduated graph, at the given flotation temperature for a grain.

When necessary, and with a better measuring technique of the flotation temperature, it is possible to reduce the measurement error in determination of the specific gravity of heavy fluids, by thermostating it down to ±0. 01° (instead of ±0. 1°), by means of quartz floats or by a differential pycnometric method by using quartz pycnometers with capillary opening [6, 12]. Further study of the temperature-specific gravity relationship for other liquids and their mixtures will provide the opportunity for selecting the most appropriate basic fluids for making up a continuous series of specific weights.

In some experiments with the flotation method, the specific gravity of a fluid is changed by pressure rather than by temperature. We believe this to be a less convenient and less promising method.

PROCESSING OF MINERALS FOR MEASURING

The flotation method affords a means of measuring mean specific gravity of a given grain, accounting for all foreign additions and assorted flaws. To reduce the error in measurement, the grain should be carefully wetted by the fluid under study, in order to prevent air bubbles from sticking to its surface. That was accomplished in the following way: coarse grains of quartz and microcline ($\geqslant$ 0. 5 mm) whose density was measured in mixtures of bromoform and alcohol were boiled for about 15 minutes in distilled water, then washed consecutively (in a watch glass or else with an eyedropper on filter paper) in alcohol, bromoform, and finally in a bromoform-alcohol mixture which was to be used in measuring the grain's specific gravity by the flotation method. The grain was then transferred to a measuring tube.

This procedure was justified by the following considerations: by boiling in water, air bubbles were removed from the grain surface which was thoroughly wetted and all cracks filled with water; the consecutive replacement of water with alcohol, of alcohol by bromoform, and of bromoform by the working mixture was done because each following pair of these fluids are mutual solvents. The grain is transferred from one fluid to another (with pincers, needle, or eyedropper) before it dries out. Of course, the method of processing a grain for measurement may vary depending on the mineral, the fluid, and the working conditions, as long as good wetting is achieved and the air bubbles eliminated. The procedure sometimes may be simplified by immersing the grain in the working fluid and examining its surface under the microscope, for bubble control.

Finer grains of quartz and microcline (about 0. 1 to 0. 5 mm) are processed directly in a glass microtester (Figure 4), by multiple rinsing with an eyedropper fitted with a very small capillary opening (0. 5 x 0. 2 mm), first with alcohol, then with bromoform, and the working fluid. This process should be observed with a binocular microscope.

DETERMINING THE FLOTATION TEMPERATURE OF A GRAIN

The flotation temperature is determined with an optional thin glass tube fitted with a ground down stopper (hollow, bottom closed) (Figure 2). It is bathed in water maintained at a constant temperature by a TS-15M ultrathermostat. Control experiments have shown that under this setup, the temperature of water in contact with the tube does not differ from that in the thermostat by more than ±0. 1° C. The velocity of the grain is determined by means of two marks (wire rings) on the outside of the tube, 50 to 100 mm apart. For fine grains, also when the mineral has about the same refractive index as the fluid and the grain is poorly visible, the observation may be done in polarized light, by means of two polaroid films in frames, placed in front and back of the measuring tube (Figure 3).

The grain is introduced into the tube at room temperature. Fine grains (about 0. 1 to 0. 5 mm) are introduced with a microtester; coarse grains ($\geqslant$ 0. 5 mm), with pincers, needle, or eyedropper. The microtester (Figure 4) is similar to the A. A. Timofeyev tube [11], with four legs welded to its bottom, instead of a handle.

The handling is done with pincers whose ends are bent to fit the microtester. With these pincers, the tube is turned upside down and back again, to see whether the mineral grain floats or sinks in a given fluid. With the tube upside down, the fluid stays in, held by the molecular force of surface tension. Another pair of pincers, with ends bent to fit the microtester base is used to convey it inside the measuring tube, bottom up (Figure 5).

After the grains have been processed preliminary to measuring, the working fluid is introduced in the microtester (enough to produce a slightly convex meniscus); at room temperature,

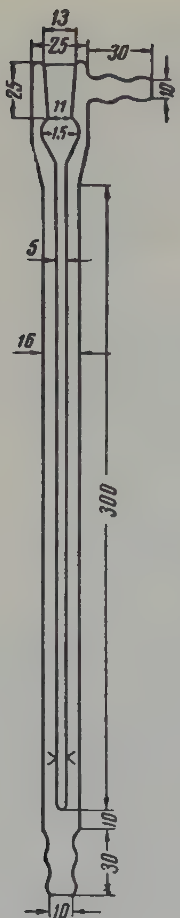

FIGURE 2.
Measuring tube

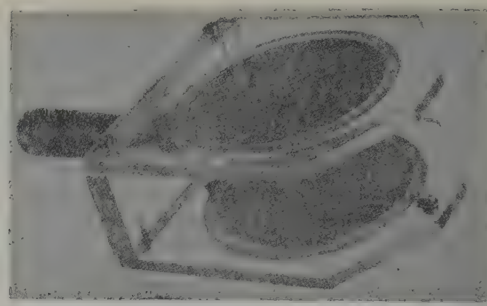

FIGURE 3. Polaroids

FIGURE 4.
Microtester

the grains in it will float to the surface. With the microtester set bottom up, the grains will float up toward the bottom. In this position, the microtester is placed with the second pair of pincers in the measuring tube where enough working fluid has been poured to have the microtester opening immersed, at room temperature. The microtester is supported by its legs in the enlarged part of the tube. As the temperature rises in the tube (and in the microtester) the specific gravity of the fluid becomes lower than that for the mineral; consequently, the grains sink, come out of the microtester, and into the measuring tube. The slightly convex meniscus in the microtester, prior to its immersion in the tube, is to prevent the formation of air bubbles at its mouth, which may hinder the escape of the grains. With the measurements completed, the tube temperature is lowered back to the room temperature, the specific gravity of the fluid becomes higher than that of the mineral, and the grains float up and are concentrated to a considerable extent back in the microtester whence they are readily extracted to be used in other analyses.

Before the experiment, the measuring tube is set up vertically, with two plumb lines (in the perpendicular planes). The vertical position is essential in order to prevent a grain from changing its position too much, with relation to the tube walls. Experience has shown that the necessary degree of verticality is readily obtained.

At some point of the rising temperature, a grain begins to sink. As it passes through the upper marker ring, a stopwatch is started and temperature T_1 measured. As the grain passes through the lower ring, the watch is stopped and temperature T_2 measured. With the distance between the rings and the time of its passage known, the velocity of the grain's fall over that distance is computed ($-V$). The fluid temperature is taken as $(T_1 + T_2)/2$. By exercising some care, it is possible to have temperatures T_1 and T_2 differ by about $1°C$ or less. After the grain has

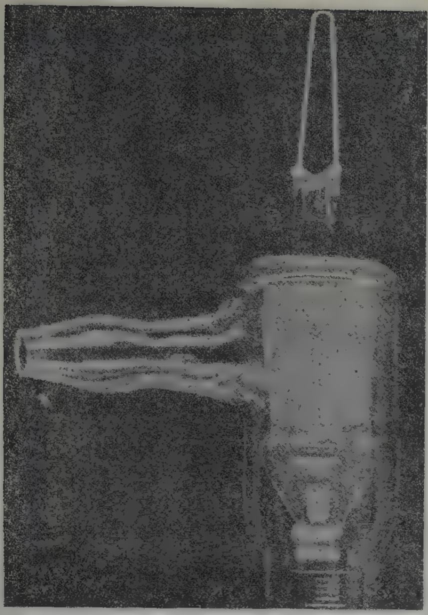

FIGURE 5. Microtester in measuring tube

passed through the second ring, the heat is turned off and cooling of the thermostat is speeded up with tap water. The grain may (if coarse) or may not (if fine) reach the bottom of the tube before the temperature drops to the point where the grain begins to rise up.

As the grain, in its upward movement, passes through the lower ring, the stopwatch is started and the temperature T_1 measured. As the grain passes the upper ring, the watch is stopped and temperature T_2 measured. After that, the cooling off is discontinued and the thermostat turned on. The grain may or may not reach the fluid surface in the tube before the temperature rises to where the grain starts sinking again. The ascending velocity (+V) and the mean temperature of the fluid, $(T_1 + T_2)/2$ are determined in the same way.

Experience has shown that three runs are sufficient for each grain. The three pairs of velocity figures are used for plotting a velocity-temperature graph by regarding the sinking velocity as negative and the ascending velocity as positive.

Theoretically, all points should fall on a straight line. As a matter of fact, they are somewhat scattered because the tube is not strictly vertical; the temperature during the grain passage between the two rings is not quite constant; the tube walls affect the grain motion differently, depending on the distance, etc. By connecting each pair of adjacent points in the upward and downward motion of the grain, we obtain three straight lines intersecting the temperature axis at different points (T', T'', T'''). Obviously, the average of the three, $T_f = (T' + T'' + T''')/3$, is the required flotation temperature for the grain, while the average absolute deviation from it, $\Delta T_f = (/T_f - T'/ + /T_f - T''/ + /T_f - T'''/)/3$ will give the mean

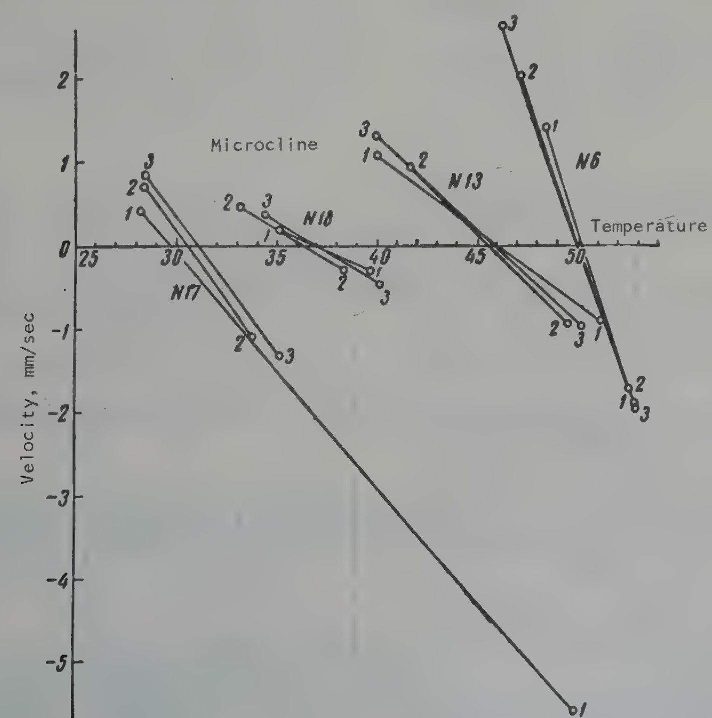

FIGURE 6. Velocity of microcline grains as function of temperature

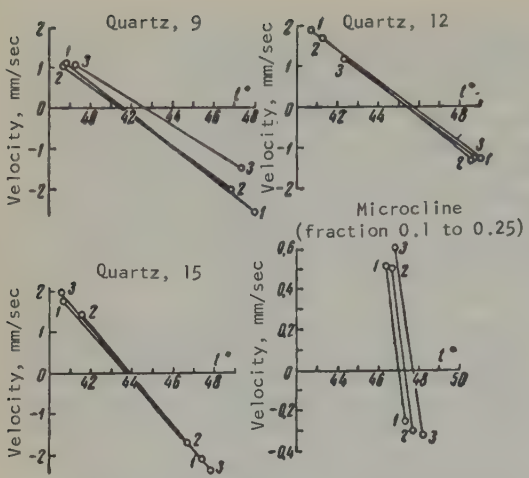

FIGURE 7. Velocity of quartz and microcline grains as function of temperature

incidental error in measuring the flotation temperature.

Figures 6 and 7 present some of the most typical velocity-temperature graphs obtained in our laboratory in determining the temperature of the grain flotation. Listed in Table 2 are the processing results for these graphs, along with the corresponding specific gravity for grains, as determined from their mean flotation temperature and the graduated curve of the working fluid (Figure 1). Table 3 presents all experimental data and computations necessary in determining the specific gravity for one of the microcline grains (No. 17).

Because of the heat lag, the true temperature of fluid at which a grain rises between the rings of a tube is somewhat lower than that indicated in Table 3, obtained from measuring the cooling water temperature. This means, however, that the true temperatures at which a grain either sinks or floats differ from one another by an amount smaller than indicated in Table 3 and Figures 6 and 7, while the true errors in measuring the flotation temperature are smaller than those indicated in Table 2.

Table 3 shows that in this measurement, as a rule, the buoying and sinking temperatures differed from the flotation temperature by 3 to 5°; on one occasion, however, this difference was almost 20°. Similar rejects have been observed more than once but they do not affect the measurement results even as much as this example shows. However, in the application of the standard "sink or float" method, this phenomenon leads to great errors in measurement. The reason for such incidental great differences in the temperature at which a grain starts moving and the flotation temperature may lie in the fact that a grain may adhere to the tube wall, at the bottom as well as on the surfact, because of rough spots on walls and on grains, surface tension of the fluid, the formation of a fine liquid film between the grain and glass, etc.

Results similar to those described here have been obtained in our laboratory in determining specific gravity for over 40 grains of microcline and quartz, in mixtures of bromoform and alchol. An analysis of all experimental data shows that the mean error in measuring the flotation temperature by this method is less than

Table 2

Experiment Nos.	Mineral, grain size in mm	Working fluid	Flotation temperature for a grain, in three measurements, 0°C			Mean flotation temperature T_f 0°C	Specific gravity of grain at flotation temperature D^t_4
			T'	T''	T'''		
9	Quartz, 3 × 1	Mixture, bromoform-alcohol (2.8% by weight)	41.6	41.4	42.6	41.9±0.5	2.638±0.001
12	" 1.8 × 0.8	Same	45.7	45.4	45,5	45.5±0.1	2.629±0.0002
15	" 2.5 × 1.5	"	43.8	43 .9	43,9	43.9±0.1	2.633±0.0002
6	Microcline, 2 × 1.2	Same, 3.66% by weight	50.1	49.9	49.8	49.9±0.1	2.558±0.0002
13	" 1.25 × 0.38	Same	46.0	45.5	45.7	45.7±0.2	2.569±0.0004
17	" 1.2 × 0.75	"	29.6	30.4	31.0	30.3±0.5	2.607±0.001
18	" 0.8 × 0.6	"	37.0	36.3	37.0	36.8±0.3	2.591±0.0006
39	" (fraction 0.1—0.25)	"	47.0	47.3	47.7	47.3±0.2	2.565±0.0004

Table 3

Experiment No.	Date	Mineral, grain size in two directions, mm	Working fluid	Upward movement T_1°C	Upward movement t_{sec}	Upward movement T_2°C	Upward movement Velocity $+V$, mm/sec	Downward movement T_1°C	Downward movement t_{sec}	Downward movement T_2°C	Downward movement Velocity $-V$, mm/sec	Flotation temperature 0°C	Error in flotation temperature, 0°C
17	5 Nov. 1959	Microcline, 1.2 × 0.75	Mixture, bromoform (96.34% by weight) and alcohol (3.66% by weight)	28.5	175	27.8	0.42	49.5	13	49.6	5.7	29.6	0.7
				28.7	103	28.0	0.72	33.0	69	34.2	1.07	30.4	0.1
				28.5	86	28.0	0.86	34.5	57	35.5	1.3	31.0	0.7

Note: The mean flotation temperature with errors is (30.3 + 0.5)°C. The average specific gravity with errors is 2.607 ± 0.001 according to the curves in Figure 1.

±0.5°C. That, in conjunction with the above-mentioned precision in determining the temperature-specific gravity relationship for the working fluid (Figure 1, the graduating graphs) makes it possible to measure specific gravity for individual mineral grains down to ±0.001. With a well-adjusted apparatus, the measurement of specific weight for each grain does not take much longer than an hour.

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Geological Institute, Academy of Sciences, U. S. S. R., Moscow

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REVIEWS AND DISCUSSIONS

LETTER TO THE EDITORIAL BOARD

by

G. V. Nekhoroshev

On the basis of field data collected in the course of many years in the Dzhungari Alatau, I deem it pertinent to offer some information on the M. P. Rusakov and G. M. Fremd paper, "A Group of Permian Volcanic Centers in the Katu Mountains (Dzhungari Alatau)", published in Izvestiya Academy of Sciences, U. S. S. R., Geologic Series, No. 3, 1960.

1. The authors' statement on their original discovery of volcanic necks and associated crater rocks in the Dzhungari Alatau (page 41) calls for an explanation.

The presence of Paleozoic volcanoes in the Dzhungari Alatau had been noted by N. G. Kassin [1] and others after him [2, 3], long before G. M. Fremd.

In his monograph, written from 1916 material, Kazakh Academy of Sciences Academician, N. G. Kassin [1] notes that "lavas pouring from craters and other features, capture and carry along fragments of the volcanic walls" (page 228). He emphasizes that "volcanoes located close to one another, poured out simultaneous flows of lavas of different composition" (page 232).

For some reason, the authors do not mention either that or the other works of students of the Dzhungari Alatau on this subject.

2. The authors' reference (page 43) to "the current concepts on an Upper Carboniferous age of this sequence (acid extrusives and pyroclastics)" in the western part of the Katu Mountains, attributed to G. V. Nekhoroshev, is a misunderstanding. It is pertinent to note, at this point, that their Figure 1 on page 42 is essentially an inexact copy of my index geologic map apprnded in a generalized form to my thesis [3], with some additional faults drawn in. On my map, to which the authors refer, only Lower and Upper Permian formations are shown for the western part of the Katu Mountains.

The authors' reference to my alleged correlation of Upper Carboniferous sequences (? G. N.) with units of the same age from the north slopes of the Dzhungari Alatau (page 43) contains another error. As a matter of fact, I do correlate, in many places, the upper Paleozoic Katu formations with similar formations in the Chulak and Digers Mountains located in extreme southwestern Dzhungari.

3. The text contains a number of contradictory statements. Thus, in order to convince the reader that our earlier assumption [3] of a Lower Permian age for acid extrusives and pyroclastics in the western part of the Katu Mountains is correct, the authors state among other things that these rocks "are traceable far to the south where the development of Permian deposits is unquestionable" (page 43) (? G. N.). This statement is confusing in view of another statement on page 41, where they correctly note that "The Katu massif is the southernmost part of the Dzhungari Alatau system..." South of the Dzhungari Alatau are the eastern reaches of the Trans-Alay Alatau, where no fossiliferous Permian deposits are known.

4. Missing in the authors' Figure 1 (page 42) is a massif of olivine gabbro located southeast of the Tekturmas sopka and changing to gabbroic ciorite described and indicated on maps of other investigators [3].

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ON THE ARTICLE BY V. V. MENNER, N. V. POKROVSKAYA, AND A. Yu. ROZANOV, "UPPER CAMBRIAN ARCHAEOCYATHID — CORALLINE ASSOCIATION IN THE TANNU-OLA RANGE, TUVA"[1,2]

by

A. G. Vologdin

The main reason for publishing the article by these authors in Izvestiya Academy of Sciences, U. S. S. R., Geologic Series, No. 7, 1960, was their alleged "law" that Archaeocyathid remains cannot be present above the upper boundary of the Lower Cambrian.

Previously N. V. Pokrovskaya assigned the Yelansk formation in the Lena middle course to the Lower Cambrian, on the basis of her findings of trilobite remains in that formation. Now archaeocyathids are known, along with trilobites, from the Yelansk formation in the Siberian platform. From her study of trilobites, Ye. V. Lermontova believed that this formation belonged to lower Middle Cambrian intervals and she assigned it to Paradoxides oelandicus and P. hicksi zones of the standard scheme for the Atlantic province. In later works on trilobites of the Yelansk, Khomustakh, and other stratigraphically correlative formations, many students, including N. V. Pokrovskaya [1], N. P. Suvorova, N. Ye. Chernysheva, V. D. Tomashpol'skaya, and others, demonstrated the presence in these formations of unquestionably Middle Cambrian forms, such as Olenoides, Koptura, Proasaphiscus, Eochuangia (?), Garphuraspis, Oryctocephalidae, and a number of genera similar to Liostracus, Solenopleura, Alokistocare (N. P. Suvorov, 1954, 1960). Collected from the same formation by N. V. Pokrovskaya and N. P. Suvorova were seemingly older forms, among them Protolenus grandis Lerm., Bergeroniellus asiaticus Lerm., Paramicmacca sibirica Lerm., Bathyuriscellus grandis Pokr., and Edelsteinaspis Lerm.

It is well known that the first group of forms is much more abundant than the second whose representatives in the middle Lena course merely reflect a paleogeographic connection between the Early and Middle Cambrian basins. The second assemblage of forms forced N. P. Suvorova, a student of Cambrian trilobites in Yakutia, to regard the Yelansk formation as "transitional" [3].

Nevertheless, N. V. Pokrovskaya decided to assign all of the Yelansk formation to the Lower Cambrian [2], without a word mentioned of the Middle Cambrian forms present there. Accordingly, the Yelansk archaeocyathids were "lowered" to the Lower Cambrian, with the resulting erroneous theory of the impossibility of their appearing in the Middle Cambrian.

As explained to this author by K. K. Zelenov, a participant in Academy of Sciences Geological Institute work in the Lena basin, the tendency for assigning the Yelansk formation to the Lower Cambrian originated in a local fault observed in its hanging wall zone. The presence of Middle Cambrian trilobites was not duly accounted for. In listing them, N. P. Suvorova noted [3] that they "usually are developed in the Middle Cambrian". If this group "usually" occurs in the Middle Cambrian, then why should it become Lower Cambrian in this instance? In a later work (1960), N. P. Suvorova stated that present in abundance in the Yelansk (Krasnoyarsk region) and Obruchev horizons are the trilobites Chondragraus minussensis Lerm., Erbia sibirica (Schm.), Kooteniella slatkovskii (Schm.), Granularia obrutchevi Polet., and species anabaraspis and kootenia, which all passed over to the Amginsk horizon, without any reduction in their numbers. Thus, the Yelansk and Amginsk horizons are connected most intimately by their fauna, which precludes their assignment to different divisions of the Cambrian. Moreover, it is known that the same Middle Cambrian trilobite assemblage is typical of other lower Middle Cambrian deposits in Siberia, where it is not accompanied by the above-mentioned "seemingly older" trilobite forms of Ye. V. Lermontova. A parallel occurrence of relatively "young" and "seemingly older" (relict) forms is not a rarity to paleontologists! There have been instances when Siberian paleontologists "took a vote" on the age of the enclosing rocks: the age of a formation was declared to be that of the majority of the fossils (!).

It should be noted that a large group of Siberian geologists, including A. G. Sivov, V. D. Tomashpol'skaya, G. G. Il'inykh, I. I. Koptev, and others, after a painstaking study of the Torgashinsk formation in the Krasnoyarsk

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[1] Po povodu stat'i V. V. Mennera, N. V. Pokrovskoy i A. Yu. Rozanova "O verkhnekembriyskom arkheotsiato-korallovom tsenoze khrebta Tannu-Ola, Tuva".

[2] Simultaneously with this manuscript, the Board received a short communication from G. N. Lukashev, supporting the views of A. G. Vologdin. Editorial Board.

region, and its analogues, definitely assigned it to the base of the Middle Cambrian. A paper on this subject by I. I. Koptev is to be published in one of the major journals. A. G. Sivov and V. D. Tomashpol'skaya have presented their valuable conclusions in 1957 (Data on the Geology of West Siberia, No. 64).

With regard to "mixed assemblages" of forms and the contradictory interpretation of their host rocks, the following remarks are pertinent. It is generally known that nearly all assemblages of fossil and living faunas and floras quite often include relict forms which have locally outlived "their age" and their contemporaries because of the comparative longevity of their local environment. Such is the Tertiary pine enduring to this day on Pitsunda Point of the Caucasian Black Sea shore; the Permian Araucaria in the Batum Botanical Garden; or even the Devonian Crossopterigii, the ancestor of amphibians; and the coelocanth fish Latimeria in the northwestern part of the Indian Ocean, north of Madagascar. However, such forms should be appreciated in the framework of the theory of facies and paleogeography, without attributing to them a stratigraphic significance to which they are not entitled.

Thus, as early as Yelansk time, archaeocyathids lived to see the Middle Cambrian epoch, at which time they did not die out, but rather lost some of their cozy ecologic niches, keeping some other ones and continued to develop under the conditions indicated in the major Salairian reconstruction of paleogeography of Eurasia and other continents and seas. This is suggested by a number of major findings of a Middle Cambrian archaeocyathid fauna in Siberia, the Sventokshish Mountains of Poland (discovered by St. Orlovskiy, 1959), some areas of the Rockies (V. I. Okulich, 1943), etc.

This author found in 1959 the first taenial archaeocyathids in the Chjan-Sya formation, at the top of the Middle Cambrian in Shantung Province, China. K. B. Korde, too, found taenian forms in the Middle Cambrian Tankhay beds, of the Lena basin. P. S. Krasnopeyeva and O. K. Poletayeva discovered an archaeocyathid in the Orlinaya Mountain, in beds transitional to the Middle Cambrian. Late representatives of Archaeocyathidae are known from the Middle Uralian Ludlow beds (according to Ye. I. Myagkova); Aphrosalpingidae are known from the Ordovician of China; etc.

With regard to the interesting finding (in Tuva collections, by G. N. Lukashev) of Archaeocythidae together with remains of an Upper Cambrian coral, it should be noted that Archaeocyathidae of a complex structure have been found in upper Cambrian intervals of Tannu-Olla. This family, in its strict meaning, was not represented in the known Lower Cambrian deposits of Siberia. It has been established on the basis of material from the Mongolian People's Republic where the Cambrian stratigraphy has not been completely worked out, as yet. There is every reason to believe that this family was among the very latest ones. It should be noted also that the two genera assigned to it have a very typical, highly organized structure of their skeletons. The coral assigned to species Cambrophyllum problematicum Howell et Fritz differs but slightly from that described by B. Howell and M. Fritz [4] who indeed were unable to obtain a precisely oriented section out of its remains; that, however, did not prevent their understanding of this form. If we reject the similarity between the Serling River coral and the North American one, the only other thing to do is to compare it with Silurian Favosites. M. Fritz, in a personal letter, acknowledged my identification of the coral as a correct one.[3]

The paper by V. V. Menner, N. V. Pokrovskaya, and A. Yu. Rozanov purports to show that the Serling coral is not a Cambrophyllum but Bija Vologdin, 1940, differing from an earlier described form, B. sibirica Vol. "by the size of its corallites and the wall thickness". On those considerations, the authors state that "the ratio of the average diameters of corallites to the wall thickness is 6.0, while it is about 2.5 for Cambrophyllum problematicum". It should be noted, however, that Bija Vologdin has no relation to corals. It is an alga of the family Solenoporaceae (Corallinaceae), whose prismatic cells have a diameter of only 0.1 mm. Its remains bear no similarity at all to true corals, either from America or from Tuva, as is obvious from the size of its cells and the overall size of its thallus. Solenoporas were best developed in the Silurian. The 1950 assignment of Bija to Alcionaraia, by this author, was a mistake which must now be corrected. To the author, who has described this material, the situation as to what is a coral and what is an alga is quite clear. I have done considerable study of algae.

The objection of the three authors that this Upper Cambrian coral "provides no new data for a precise age determination" is not valid because the American material comes from the Cedaria zone, the lower Maurice formation, Lower Dresbachian (lower Upper Cambrian), Montana. The three authors did not take the trouble to get acquainted with the paleontology of the Cedaria zone, in the works of Howell and Duncan, 1939; Lochman and Duncan, 1944, and others.

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